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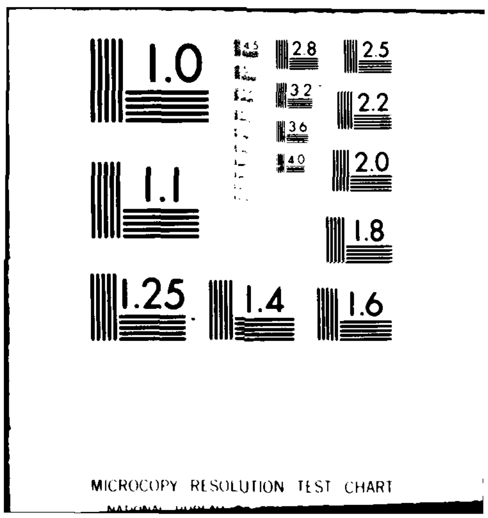
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(9) Master's thesis

(6) THE LOGAIR ROUTE STRUCTURE: AN EXPLORATION OF THE SINGLE-HUB CONCEPT

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This thesis examined the feasibility of a single-hub route structure concept. This represents a marked departure from the present trunk-and-feeder route structure which utilizes multiple hubs of operation. The idea was based upon the routing network used by several commercial air freight carriers. A computerized simulation program, SIMSCRIPT II.5, was employed to evaluate a single-hub structure incorporating as many real world constraints as was feasible. System performance was simulated for a 90-day time period. Results indicated that a single-hub route structure could provide next day delivery for practically all priority one, two, and three cargo. In comparison to the trunk-and-feeder system, transit time was improved by 0.22 days (17.9%). But contract operating costs (based on FY 80 figures) increased by $9,354,000 (19.6%). Furthermore, 23 aircraft were required versus 15 under the present system for CONUS operations. This increased cost was counterbalanced by a projected savings of $10,700,000 annually in spares inventory to be realized by a faster supply pipeline.

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THE LOGAIR ROUTE STRUCTURE: AN EXPLORATION OF THE SINGLE-HUB CONCEPT

A Thesis

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Logistics Management

By

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June 1980

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has been accepted by the undersigned on behalf of the faculty of the School of Systems and Logistics in partial fulfillment of the requirements for the degree of

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James W. Masters
COMMITTEE CHAIRMAN

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CHAPTER I

INTRODUCTION

Background

The United States Air Force contracts for the movement of high-priority materiel for weapon system support via a commercial contract carrier operation known as Logistic Airlift (LOGAIR). In the contiguous United States, the LOGAIR network connects selected Air Force and Navy installations with the five Air Logistic Centers (ALCs), which provide the bulk of the materiel support (24:9-10).

Air Force Manual 76-1, The LOGAIR Traffic Manual, states the objectives of the system as follows:

1. Establish and maintain a cargo airlift service,
2. Improve the effectiveness and timeliness of logistical support by expanding and improving the utilization of air transport, and
3. Improve the reliability and quality of the system (29:3-1).

The basic concept behind LOGAIR is the rapid movement of high-priority cargo.[1] The Air Force incurs the higher

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[1]LOGAIR supports transportation priorities (TP) 1 and 2 primarily. Priority 3 cargo is carried on a space available basis. Transportation priority codes are determined from the published matrix of Force/Activity Designator Codes Versus Urgency of Need Codes (29:1).

cost of shipping by air to achieve the advantage of speed. The routing structure used to facilitate air shipments is a trunk-and-feeder line system. Trunk, or main lines, connect the five ALCs, AFLC Headquarters, and Aerial Ports of Embarkation (APOEs). Feeder lines are subsidiary routes which connect individual user installations with the trunk lines. The FY79 LOGAIR Route Structure (see Figure 1) utilized six trunk routes and seven feeder routes. One alternative structure is a single-hub network. Under this concept, all freight is shipped to a central location, sorted, and reloaded on aircraft for its final destination. This route configuration has proven beneficial for several commercial air freight carriers (e.g. Federal Express Corp., Emery Air Freight, and Purolator Express) where overnight service has become the norm (21).

LOGAIR currently uses two types of aircraft: the L-100 provides outsize cargo lift capability for items such as aircraft engines, the L-188 augments the L-100 due to its faster speed and more economical operating costs. Current AFLC policy is to limit L-100 service to the AFLCs, HQ AFLC, and the APOEs (23:iii-iv; 32).

The highest priority one category, MICAP,[2] now comprises approximately 14 percent of LOGAIR traffic (35:3).

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[2]Those items which affect Mission Capability (formerly called NORS) (29:3).

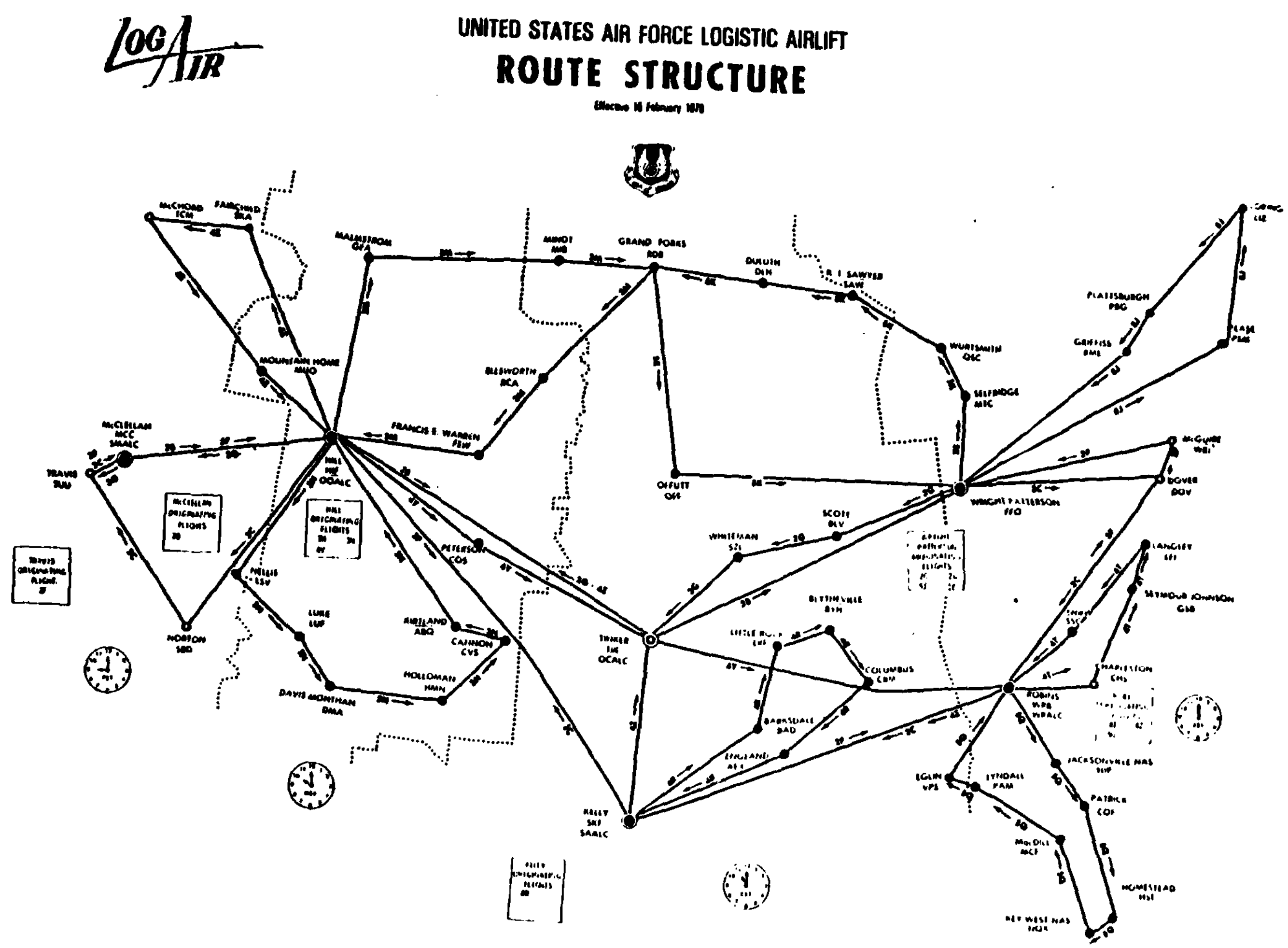

Figure 1

U.S. Air Force LOGAIR Route Structure for FY 79

While LOGAIR asserts an average of 2.5 days MICAP transit time,[3] MICAP items that affect major weapon systems are increasingly being shipped by other modes which can provide more speed (35:3).

As LOGAIR contract managers, AFLC/LOM re-evaluates and restructures the network annually with the criteria of reducing direct operating costs which are based on air miles flown and number of landings while maintaining shipment transit times at acceptable levels. There is increasing concern at HQ USAF that more emphasis should be given to reducing transit times, even at the expense of increasing direct operating costs (21). Reducing the amount of time that a component is in the supply pipeline has a two-fold benefit. A quicker pipeline allows a smaller investment in inventory and reduces the time a weapon system is out of commission due to a parts supply shortage.

Significance of the Study Effort

The Air Staff believes a tremendous potential exists for savings should LOGAIR transit times be significantly reduced. Mr. Dale Sampson of the Logistics Management Center (LMC) cites a hypothetical example:

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[3]As used in this chapter, transit time refers to the amount of time required for a shipment to travel from origin to destination plus the period that the shipment is initially held awaiting transport, referred to as hold time.

> . . . Suppose a major command has 100 of a certain type of aircraft in its inventory of which 20% are down for parts, on the average, at any given time. If we can reduce transit time by 50%, then, over the long run, that commander will have 10 more aircraft available for mission flights or contingencies. This is roughly the same as having 10 additional aircraft in your fleet at a fraction of the cost [21].

This rationale is one method of attempting to quantify the opportunity cost of a weapon system out of commission due to parts shortage.

The time lag incurred in receiving parts, coupled with limited war readiness spares kits (WRSK), reduced budgeting for spares, and the increased complexity of weapon systems contribute to an overall reduction in readiness. The difficulty in obtaining spares in a timely manner is undoubtedly reflected in lower rates of operational readiness experienced in recent years (35:4). Excessive transit times, coupled with increasingly expensive spare parts,[4] yield a pipeline that requires more and more dollars to maintain. Although the Air Force can do little to control the rising costs of weapon system spares, inventory investment can be reduced by shortening transit times (13).

The implicit savings of a higher percentage of aircraft in commission, plus the savings of a reduced spares inventory required to support a faster supply pipeline, warrant the investigation of a route structure which places emphasis on

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[4]In 1978, the DOD average value of a single issue item was $885 while the Air Force ALCs' average was $3344 per item issued (31:27).

reducing transit times rather than reducing direct operating costs. Specifically, the LMC has expressed interest in further exploration of a single-hub network (21).

Objective

The objective of this thesis was to construct a single-hub network utilizing realistic cargo shipment demand requirements and as many other real world constraints as was possible. After the route was constructed, its performance was estimated by computer simulation to determine its ability to reduce overall system transit time.

Research Questions

To meet these objectives, this study answers the following research questions:

1. Does a single-hub route structure yield lower transit times than the trunk-and-feeder system?

2. What will be the impact on contract direct operating costs of a single-hub route?

3. If a single-hub system does produce faster transit times, to what degree will faster transit times lower inventory investment required to support the supply pipeline?

Overview of Study

Chapter II discusses previous LOGAIR studies. Various methodologies amenable to vehicle routing type problems are briefly presented. The technique selected for the route generation is a modification of a ray-sweeping approach

incorporating a vehicle scheduling algorithm. The characteristics of the ray-sweeping algorithm are discussed and its applicability to the problem is shown.

Chapter III explains in detail the methodology used in approaching the problem. Sources of data, research design, and operational definition of variables are explained. Detailed explanations of the ray-sweeping algorithm and all heuristics employed are presented. And finally, all of the preceding concepts are addressed in their relation to the research questions.

Chapter IV presents the results and findings of the study. It was found that the single-hub system could decrease overall transit time from an average of 1.23 days to 1.01 days. However, the resulting increase in operational costs alone was $9,354,000. This expenditure was countered by a predicted savings in inventory investment of $10,700,000.

Chapter V contains the conclusions and summary of the study. Recommendations for AFLC management as well as future research efforts are included.

CHAPTER II

LITERATURE REVIEW

Overview of the Chapter

Because of the potential benefits to be derived from an improved system, LOGAIR has been the subject of several studies. In the past, most studies and reports have attempted to improve the cost and/or time aspects of the system without changing its basic structure. The first part of this chapter examines several of the most recent of these studies, including their techniques and limitations. The latter section discusses the family of heuristic vehicle routing problem methodologies, including three types of routines: improvement, ray-sweeping, and savings. The chapter concludes with a justification of the use of the ray-sweeping approach to the vehicle routing problem at hand.

LOGAIR Studies

A study by Fetter and Steorts of Rand Corporation, conducted in 1966, presented a computer model designed to evaluate the costs of the existing trunk-and-feeder line system. The Rand model evaluated alternative routes within the current structure based on change in cargo requirements (5:21). It now is the basis for the cargo requirements matrix generator that AFLC/LOM uses as input to their manual route design

process (17).

More recently, Captains Michael McPherson and Brian O'Hara attempted to develop a computerized linear-programming model that minimized operating costs of LOGAIR trunk routes (16). Their model did not, however, consider transit times or pipeline costs. It also failed to address the LOGAIR system as a whole because of limitations in the linear-programming package used to optimize the model.

While McPherson and O'Hara attempted to minimize operating costs on the trunk lines, Major Kenneth Moberly and Captain Theodore Gorychka came closer to solving the transit time problem. In their AFIT master's thesis, Moberly and Gorychka attempted to minimize pipeline time along the current LOGAIR route structure (14). They attempted to use linear programming to develop a flight schedule that minimized the time any shipment spent awaiting transhipment.[5] Moberly and Gorychka recognized that their results were highly dependent on the current route structure (14:48). The optimality of their model was limited because the then-current route structure was not optimal (14:49).

Other studies have attempted to use transit times as performance criteria for improving the LOGAIR system, but these have mainly concentrated on minimizing operating cost

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[5]Time awaiting transhipment is the time interval a shipment waits at intermediate station(s) for reloading and redeparture for its final destination.

within the constraint that transit times not be further degraded.[6]

None of the studies prior to 1979 attempted to examine the LOGAIR system to determine what improvements in transit time could be gained from modifying the route structure. In a 1979 Air Command and Staff College research report, Major Nicholas Van Valkenburgh described a radically different LOGAIR route structure with the primary objective of reducing transit times. Van Valkenburgh's system was based on the highly successful airborne package express service run by Federal Express Corporation.

Federal Express Concept

Federal Express utilizes a single hub of operations concept. The basis of the hub concept for any transportation network is a single distribution point located near the "center of gravity of the network."[7]

Memphis, Tennessee, was chosen by Federal Express as their hub because of its excellent flying weather and its proximity to their "center of gravity" of package movements (35:24). All packages are flown from outlying cities into the hub, where they are offloaded, sorted, and reloaded on

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[6]See Boudreaux and Olansen (1) and Prescott and Palmatier (18).

[7]The Center of Gravity is defined as the point that minimizes the total transport costs (12:262), distance traveled, or transit time to all other nodes in the system (2:309).

aircraft to leave the next morning. This allows Federal Express to provide overnight service from any location to another of 97 cities in their network. This differs from the LOGAIR concept which moves cargo from origin to destination via a network of interconnecting, circular routes.

It is interesting to note that Federal Express had originally planned to expand to regional mini-hub terminals to cope with increased volume, but chose instead to enlarge their central operation at Memphis (35:27).

Van Valkenburgh's Mark 2 Model

Van Valkenburgh speculated that a similar system for the "on-line" LOGAIR bases would yield considerable improvement in transit times. The results of Van Valkenburgh's study tended to support his original idea.

Since this thesis uses the Van Valkenburgh study as a conceptual starting point, it is useful to review the major assumptions and design considerations of his LOGAIR Mark 2 model. Van Valkenburgh limited himself to applying the single hub concept to the existing LOGAIR system. Furthermore, he made these assumptions to simplify the design of his hub model:

--High priority cargo airlift requirements and number of trips per week for each base are the same as under the current system,

--Flying times are standardized based on length of the leg being flown,

--The same type aircraft are used and their payloads are similar,

--Ground handling times are assumed to be half an hour for user bases and an hour for ALCs/APOEs,

--The same bases must be served as under the then-current system,

--Bases within one hundred miles of an ALC are served by dedicated ground transport,

--A hub terminal capable of handling all cargo on the system is available at the hub base,

--The hub is located at Tinker AFB, OK (35:29-36).

These assumptions were necessary because Van Valkenburgh's study was conducted without computer assistance. Without these simplifications, it is doubtful that the LOGAIR Mark 2 model could have been developed manually in the limited time available to Major Van Valkenburgh.

After Van Valkenburgh defined his limiting assumptions, he developed a heuristic route planning algorithm which yielded routes that met the cargo tonnage requirements of the current LOGAIR system while minimizing transit times. Basically, the algorithm selected an aircraft type, then built a tentative route by connecting one or more bases to the hub by a straight line. If the average daily cargo tonnage to be onloaded and offloaded at those bases did not fill the aircraft to capacity, the nearest base to the tentative route was added to the route. Bases were added until the aircraft's capacity was used. Then a check was made to see if more bases could

be added if a larger aircraft (selected from among the types available under the contract) were used. If so, those bases were added; if not, the route was finished and the process started over with another base (35:37-40). When all the routes were completed, they were adjusted to insure that no route required an estimated flying time of over 24 hours, and that transit times were roughly equal for all routes. The final route structure that emerged from this process is shown in Figure 2.

The key factor of the LOGAIR Mark 2 model was that it represented a conceptual break from past studies of the LOGAIR system. As shown above, all previous efforts had concentrated on optimizing costs or schedules of the current, multi-hub, trunk-and-feeder line system. The LOGAIR Mark 2 study, on the other hand, introduced a new way of approaching logistics support for high priority cargo. It was, however, intended primarily to demonstrate a concept, not to support an operational decision (35:6).

Before LOGAIR Mark 2, or any single-hub model, can be used to support operational decisions, the conceptual and design factors that limit the LOGAIR Mark 2 model must be overcome. Van Valkenburgh admitted that he made no attempt to optimize his route structure. He used highly aggregated freight volumes (i.e. average daily tonnage for several years) and he examined hypothetical changes in transit times for three SAC bases in the network. It is difficult to see how these results could be expanded for the entire system based

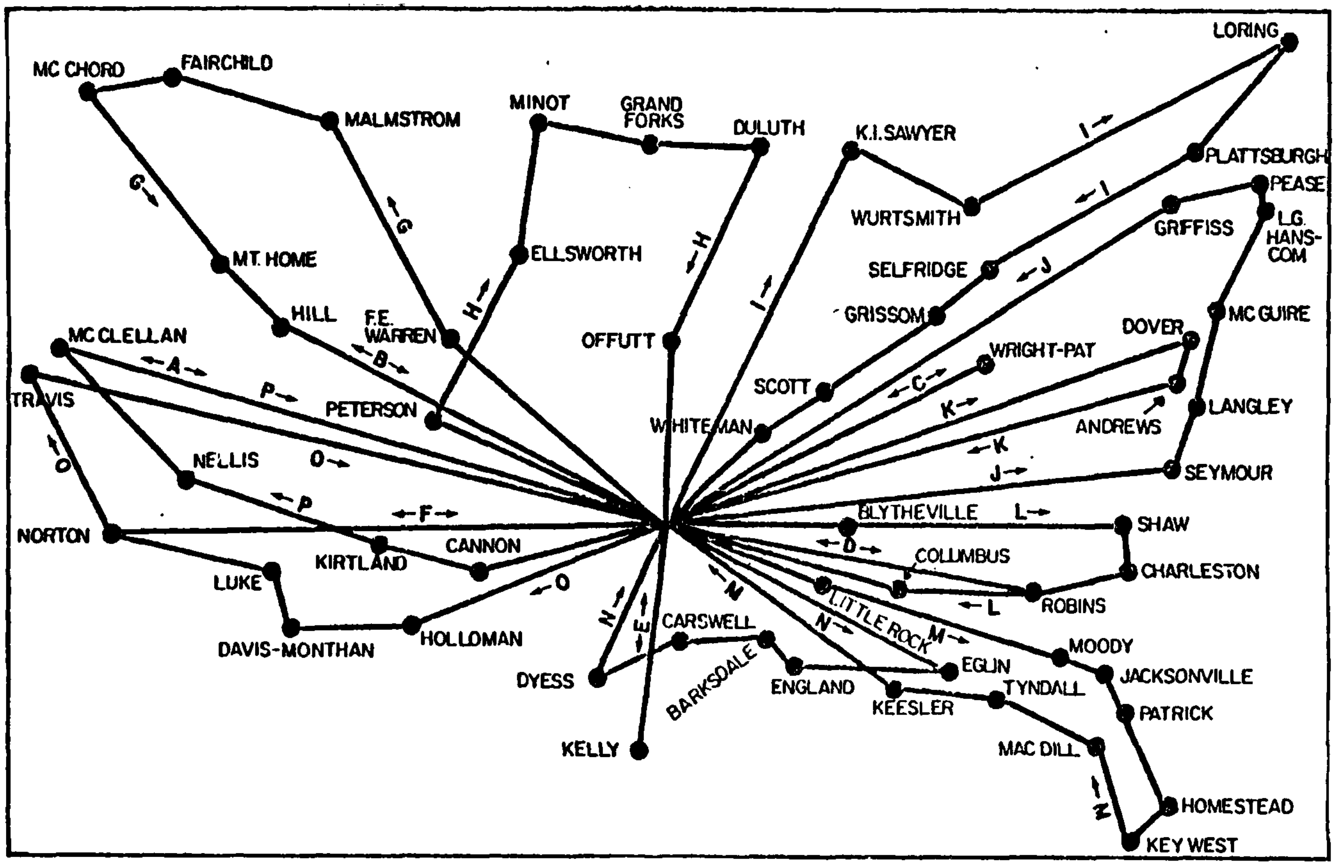

Figure 2

Mark 2 Route Structure

on such a narrowly focused sample. Some experts in management science indicate that the methods Van Valkenburgh used to arrive at performance factors for LOGAIR Mark 2 are of dubious value (13; 6:1). However, as Van Valkenburgh stated: "The model route structure . . . should be viewed as a departure point for possible future study rather than a definitive solution [35:6]."

Available Methodologies

The LOGAIR routing problem is one of a family of well-known problems that go by the generic name of vehicle routing problems (VRP). These problems have received a great deal of attention in operations research literature in the past twenty years and can be said to be generally well understood (15:250). In the terminology of operations research literature, the VRP can be stated as follows: Given a set of demand points, usually called nodes or stations, and supply points, called hubs or depots, find the set of paths between nodes and hubs (or nodes and other nodes) that minimizes the cost of satisfying the demands. The individual paths are usually referred to as links or routes, and a set of links is called a network or route structure.

Vehicle routing problem analysis lends itself to the LOGAIR situation for several reasons:

--once routes are determined, they remain relatively static for the fiscal year. Under the present structure, aircraft can be diverted to off-route bases or directed to

overfly certain bases on an emergency or mission essential basis. However, these deviations are the exception rather than the rule.

--Vehicle (aircraft) parameters such as cargo capacity, speed and range are highly deterministic in nature and serve as sharply defined constraints on the routing problem.

--Customer requirements (inbound and outbound cargo) are readily determinable from AFLC planning data and can be stochastically generated by simulation techniques to approximate real-world user demands.

--The minimization of distance traveled is of high interest because air miles flown is one of the bases of contract direct operating costs. Reduction of air miles will also naturally reduce fuel consumption.

The VRP can be approached with several available methodologies; for example, via linear programming, as was done by Foster and Ryan (15:248), Balinski and Quandt (15:248), and the thesis teams discussed earlier. The difficulty with this approach lies in its computational complexity. To determine a network of even moderate size requires a large number of constraints and a great amount of computer storage. In fact, as Captains McPherson and O'Hara noted in their thesis, generation of routes containing more than 15 or so nodes cannot be handled by most commercially available linear programming packages (16:24).

Due to the limitations of linear programming solution to the VRP, several heuristic techniques have been developed

that result in near optimal solutions at greatly reduced cost in computer time and storage. These heuristics may be classified in three general categories: improvement routines, savings routines, and ray-sweeping routines.

Improvement routines basically build a simple route structure by selecting links at random, then examine the structure to see if improvement can be made by replacing any set of "n" links with any other set of "n" links. The resulting tours are called "n optimal," where "n" is the largest number of links for which optimality can be theoretically demonstrated. Proponents of the "n optimal" improvement routine include Christofides and Eilon, Lin, Carg and Thompson, and Lin and Kernighan (15:246). These methods have been demonstrated to provide optimal or near-optimal solutions to problems involving as many as 100 nodes in less than 30 minutes of computer time (15:246). However, there is some question as to the suitability of these methods for problems involving many active constraints. Furthermore, the routes generated tend to be circular rather than petal-shaped. Narrow, petal-shaped routes are preferable to circular routes because the broader the route, the greater the probability that the route contains links that are longer than they should be (15:248).

The savings approach concentrates on reducing travel time by building up a network consisting of a series of out-and-back trips from a central depot to each node in a sequential manner as if done by a single vehicle. It then attempts

to save time by linking two customers together in substitution for one link between the depot and each customer (15: 247). Since two routes are permitted to be merged by replacing links adjoining the depot, the time savings that accrue are cumulative. Routes continue to be merged until some vehicle capacity constraint would be violated by adding additional links. Mole points out several criticisms of this approach (15:247-248). Since only links adjoining the depot are removed, no attempt is made to examine savings that might accrue from exchanging links between customers in the middle of the routes. The savings approach may be inappropriate for the LOGAIR problem, however, because it places emphasis on improving time required to travel the entire network rather than individual routes. One of the greatest disadvantages of the savings approach, as discovered by its proponents,[8] is its tendency to produce individual routes that overlap. It can easily be demonstrated that overlapping and/or crossing routes are not optimal with respect to minimizing distance traveled (15:247-248; 34:344). Therefore, any heuristic that may produce such routes would not be optimal.

In contrast to the other two approaches, ray-sweeping algorithms are based on the notion that narrow, petal-shaped routes are preferable to broad, overlapping routes since the latter include many "overly-long" links (15:248).

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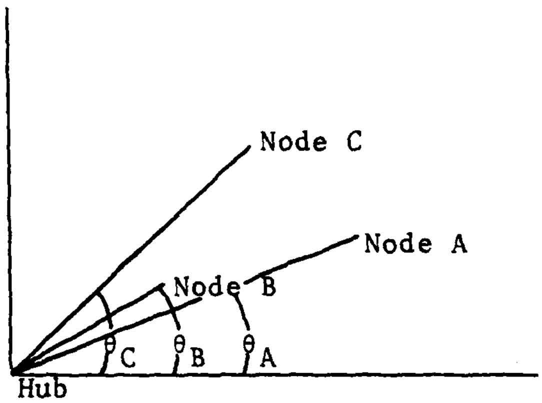
[8]Dantzig and Ramser, Clarke and Wright, Fletcher and Clarke, and Gaskell (15:247).

In general, the ray-sweeping algorithm generates a list of nodes sorted in order of coordinate angle from the central depot (see Figure 3). These nodes are then connected in order until some constraint is violated. Most of these methods then employ a refinement procedure to see if additional savings can be gained by reallocating some nodes between routes. These methods differ mainly in how the coordinate system is defined and aligned. Wren and Holliday align their coordinates along the most sparse direction and then rotate the coordinate axis through 360 degrees in steps of 90 degrees. At each step a network is generated and the best of the four networks is chosen as optimal (34:335-337).

Gillette and Miller, and Gillette and Johnson, on the other hand, pick an arbitrary starting direction and then realign the coordinate axis through each node in sequence until a 360 degree rotation is completed. This generates "n" networks where "n" equals the number of nodes in the system. They then reverse the procedure, sweeping backwards to develop "n" slightly different networks. Finally, the best of the "2n" networks is selected as the optimal (15: 248). Mole points out that all ray-sweeping methods produce networks of similar quality in similar amount of computer time (15:248-249).

A:



Nodes are added to route in order of increasing angles θ, i.e. A, B, C, as in Figure 3A, until a cargo or time constraint is reached. Then the algorithm links the nodes in a manner that minimizes total distance between nodes, i.e. B, A, C, as illustrated in Figure 3B.

B:

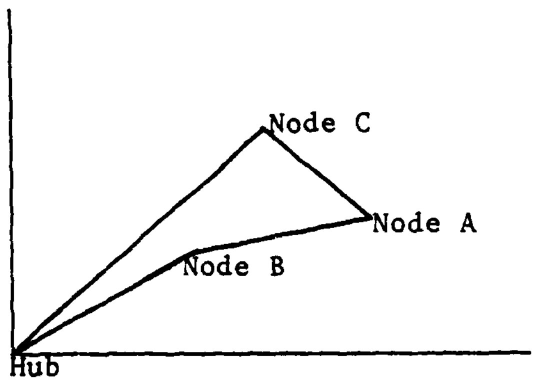


Figure 3

Illustration of the Ray-Sweeping Algorithm (34:336-337)

CHAPTER III

METHODOLOGY

Overview of the Chapter

This chapter covers three main topic areas: a general description of the variables, assumptions, and limitations of the computerized network generator program, a detailed description of how the generator program works and how its output was modified, a description of the simulation of the central hub network and how its performance was compared to the present LOGAIR route structure, and finally sources of data and justification of their use are discussed.

Research Design

The research design consisted of three basic steps: determining the route structure by means of the ray-sweeping algorithm, simulating the performance of the route over a 90-day period, plus evaluating its performance and comparing that performance to that of the LOGAIR route structure as it existed over the same 90-day period (October-December 1979). This period was selected because it was the most recent completed quarterly data compiled at the time of the research effort, and HQ AFLC personnel felt that it would be representative of the annual performance of the entire system. Furthermore, these three months contained a mix of good and

bad flying weather, which is representative of the weather throughout the year (19).

The period of the data and the run of the simulation were limited to 90 days because the researchers felt that any longer a period would produce an overabundance of both data and computer run-time required to complete the simulation.

Variables. The following were used in the model computations:

--Distance - the straight line distance in nautical miles between two nodes (bases) in the system. This mileage is derived by the program by means of reading the coordinates of the node pairs and calculating the distance. Coordinates fed into the program were measured from a standard navigational chart for which a special grid was constructed. Standard longitude and latitude were not used because the phenomenon of converging meridians would have distorted the vertical axis component at the higher latitudes. This variable was used in the route generator only.

--Cargo tonnage (W) - the mean daily weight of cargo, to the nearest 1/100 ton, originating or terminating at any node in the system. The mean weights were used as the parameters in generating stochastic cargo requirements in the simulation.

--Route Segment Time - time required, to the nearest 1/10 hour, for the aircraft to fly from one node to the subsequent node in its route. It was computed by dividing nautical mile distance by an average groundspeed (286 knots

for L-100 and 358 knots for L-188 (23:ii-iv)) and adding 20 minutes for approach and landing time. This variable was used in the simulation model only.

--Transit time (TT) - the time required in days, to the nearest 1/100 day, for a shipment to travel from origin to final destination. It included actual time in flight and transhipment time.

These variables were used to develop the measure of system performance by which the existing route structure and the central hub system were compared. This measure was:

--weighted transit time - the amount of time in days, to the nearest 1/100 day, required for a shipment to travel from origin to final destination, weighted by the volume of cargo, in tons, shipped between those nodes. This value represented the performance of an individual node pair in the system. It was used to evaluate system transit time.

--system transit time (STT) - an evaluation of the entire route network arrived at by means of the following formula:

$$STT = \frac{\Sigma\Sigma(W_{ij} \cdot TT_{ij})}{\Sigma\Sigma W_{ij}}$$

where W_{ij} is the weight shipped from node i to node j; TT_{ij} is the transit time from i to j.

Even though present reporting procedures reflect a straight average transit time, the researchers felt system transit time should be weighted in order for it to more accurately indicate overall performance. This weighting

factor would prevent, for example, distortion caused by introducing a large number of small (lightweight) shipments transported over a frequently serviced link, or by exceptionally fast service to infrequent users of the system.

Model Construction. This section describes the operation of the two routines, the network generator and the simulation, in detail. The inputs and outputs of each routine are described, and the algorithms used to manipulate the data are outlined. Both programs were run on the HQ AFLC Honeywell/GE 635 computer. The route generator was written in Honeywell's version of FORTRAN, while the simulation was coded in Consolidated Analysis Center Incorporated's H6000/SIMSCRIPT II.5.

The network generator routine read a computer file that contained the grid locations, in degrees to the nearest 1/10 degree, of each base in the network, the grid location of the central hub, cargo tonnage originating and terminating at each base, and the constraints (e.g. total time per route, vehicle capacity) the network was subject to. The network was constructed using Gillett and Miller's single-hub vehicle dispatch algorithm incorporating changes suggested by Elio Conto (3; 7). This algorithm was chosen from among the ray-sweeping algorithms because it was capable of generating routes covering a large number of bases in a very short time,[9]

[9]The lack of an algorithm that could handle a large number of bases in a reasonable amount of computer time severely limited past LOGAIR studies (1:17; 18:23).

Gillett and Miller's algorithm has been tested on problems involving up to 100 nodes. It requires 233 seconds of computer time to solve "typical" 100-node problems (7:346).

it was simple to program, and it has been demonstrated to produce better results than any of the other available heuristics (3:186, 188; 7:346-347). Gillett and Miller's algorithm worked basically as follows: all bases were numbered according to the size of their polar coordinate angle when the hub was used as the origin. Starting with the base with the smallest angle, the algorithm added bases to the route in order of increasing polar coordinate angle until some constraint (route length and/or vehicle capacity[10]) was exceeded by adding another base. It then built a second route in the same manner, but used the base with the smallest polar coordinate angle that was not included in the first route as the first stop. This process continued until all bases were included in a route. The results was a network of non-overlapping routes emanating from the central hub like the petals of a flower. Each route was then evaluated and the order of the bases adjusted, if necessary, to minimize transit time on that route. Then the entire route network was evaluated to determine if shifting bases between routes would produce an improvement in transit time for the network. The entire algorithm was repeated using the base with second lowest polar coordinate angle as a starting place, then again with the third lowest, and so on until each base was used as a starting point. Finally, all of the above steps were repeated, but the bases

[10]See Data Sources for aircraft capacity figures. Route length was constrained to 16 hours to allow 8 hours for cargo turnaround at the hub.

were assigned to routes in order of <u>decreasing</u> polar coordinate angle starting from the base with the <u>largest</u> angle. This method produced "2n" networks (where "n" is the number of bases assigned to the network), each with a slightly different structure and length.

The route structure thus produced was an initial feasible solution. However, manual adjustment was required to yield a more effective network (see Figure 4). This resulted in overlapping of some routes, interchanging nodes, reversing the flow of certain petals, and directing the type of aircraft to be used for a particular base. These changes were required because:

--the number of aircraft required by the initial solution was too high. Even though contract costs are a function of air miles flown, compensation rate per mile would naturally have to increase to reflect higher fixed costs associated with a larger fleet.

--special networks traits were desirable. As mentioned earlier, it is current AFLC policy to provide ALCs, APOEs and HQ AFLC with L-100 service.

--the direction of flight of some routes was reversed. This enabled some routes to be combined (serviced by one aircraft). To illustrate, consider the situation where two bases are served on a route. Base "A" receives 10 tons from the hub and returns 2 tons. Base "B" receives 3 tons and returns 10 tons. The capacity of the aircraft is 15 tons. By flying to Base "A" first rather than "B", the cargo

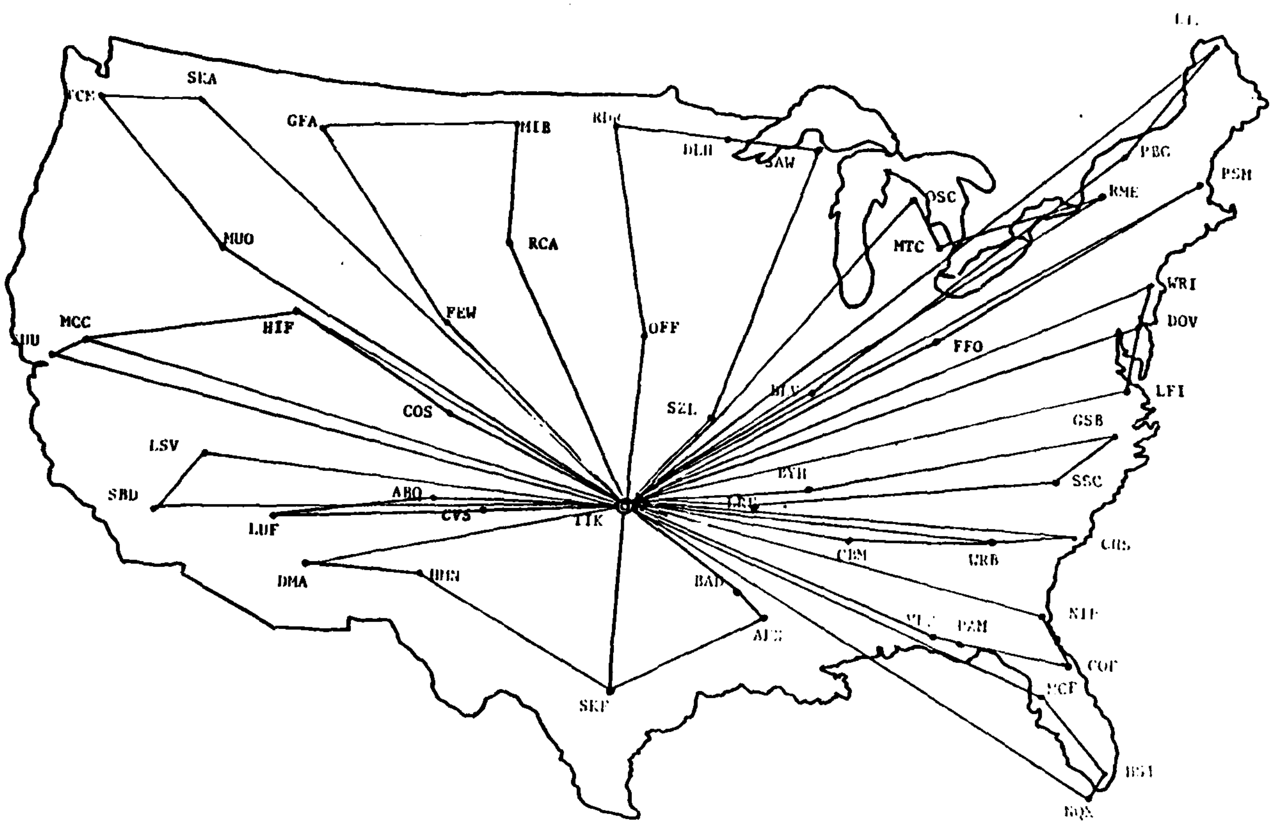


Figure 4

Revised Central Hub Network

TABLE I

Alphabetical Listing of Three-Letter Location Identifiers

Identifier	Station and Geographical Location
ABQ	Kirtland AFB NM (Albuquerque)
AEX	England AFB LA (Alexandria)
BAD	Barksdale AFB LA (Shreveport)
BLV	Scott AFB IL (Bellville)
BYH	Blytheville AFB AR (Blytheville)
CBM	Columbus AFB MS (Columbus)
CHS	Charleston AFB SC (Charleston)
COF	Patrick AFB FL (Cocoa Beach)
COS	Peterson AFB CO (Colorado Springs)
CVS	Cannon AFB NM (Clovis)
DLH	Duluth Int'l Airport MN (Duluth)
DMA	Davis-Monthan AFB AZ (Tucson)
DOV	Dover AFB DE (Dover)
FEW	Francis E. Warren AFB WY (Cheyenne)
FFO	Wright-Patterson AFB OH (Dayton)
GFA	Malmstrom AFB MT (Great Falls)
GSB	Seymour-Johnson AFB NC (Goldsboro)
HIF	Hill AFB UT (Ogden)
HMN	Holloman AFB NM (Alamogordo)
HST	Homestead AFB FL (Miami)
LFI	Langley AFB VA (Newport News)
LIZ	Loring AFB ME (Limestone)
LRF	Little Rock AFB AR (Jacksonville)
LSV	Nellis AFB NV (Las Vegas)
LUF	Luke AFB AZ (Phoenix)
MCC	McClellan AFB CA (Sacramento)
MCF	MacDill AFB FL (Tampa)
MIB	Minot AFB ND (Minot)

TABLE I, continued

Identifier	Station and Geographical Location
MTC	Selfridge ANG MI (Mount Clemens)
MUO	Mountain Home AFB ID (Mountain Home)
NIP	Jacksonville NAS FL (Jacksonville)
NQX	Key West NAS FL (Boca Chica, Key West)
OFF	Offutt AFB NE (Omaha)
OSC	Wurtsmith AFB MI (Oscoda)
PAM	Tyndall AFB FL (Panama City)
PBG	Plattsburgh AFB NY (Plattsburgh)
PSM	Pease AFB NH (Portsmouth)
RCA	Ellsworth AFB SD (Rapid City)
RDR	Grand Forks AFB ND (Grand Forks)
RME	Griffiss AFB NY (Rome)
SAW	K.I. Sawyer AFB MI (Marquette)
SBD	Norton AFB CA (San Bernardino)
SKA	Fairchild AFB WA (Spokane)
SKF	Kelly AFB TX (San Antonio)
SSC	Shaw AFB SC (Sumter)
SUU	Travis AFB CA (Fairfield)
SZL	Whiteman AFB MO (Knobnoster)
TCM	McChord AFB WA (Tacoma)
TIK	Tinker AFB OK (Oklahoma City)
VPS	Eglin AFB FL (Valparaiso)
WRB	Robins AFB GA (Warner Robins)
WRI	McGuire AFB NJ (Wrightstown)

requirement can be handled by one aircraft (see Table II).

In explaining the characteristics of the simulation, the flow of one day's operation is detailed below:

Initially, outbound cargo for each base was generated. These cargo requirements had the following attributes:

TABLE II

Cargo Sequencing Problem

Route #1 - Tinker-to-B-to-A-to-Tinker		
Location	Action	Load on Take off
TIK	Depart	13 tons
B	Offload 3 tons, onload 5 tons, leaving 5 tons	15 tons
A	Offload 10 tons, onload 2 tons, leaving none	7 tons
COMMENT:	5 tons of cargo left at location B must be carried by another aircraft	
Route #2 - Tinker-to-A-to-B-to-Tinker		
Location	Action	Load on Take Off
TIK	Depart	13 tons
A	Offload 10 tons, onload 2 tons, leaving none	5 tons
B	Offload 3 tons, onload 10 tons, leaving none	12 tons
COMMENT:	All requirements satisfied	

--weight in tons - this figure is a random variable selected from a probability distribution derived from a sample of 768 actual shipments chosen at random (see data sources for validation of this parameter).

--destination - all weight generated from any given base to another base on any given day was assumed to be part of one shipment. Destination was annotated by a base

identification number.

--Release time - time, in simulation units, that the shipment was made available from the originating base. This was the same as aircraft arrival time.

--Route number of destination base - a means of identification by which the program sorted cargo at the hub and scheduled it for shipment.

Next, flights were originated from the hub. Each flight included all cargo outbound for any base on a single route, up to the capacity of the airplane. Any cargo that caused the aircraft to exceed its weight capacity remained at the hub and was included on the next flight for that particular destination. The flight time from the hub to the first scheduled stop on each route, as well as each subsequent stop, was loaded by means of a separate data matrix. At each base on the route, cargo for that base was subtracted from the aircraft load and outbound cargo from that base was added to the load, not to exceed aircraft cargo capacity. Any outbound cargo from a base that could not be included on a flight waited for the next arriving flight. The aircraft continued in this manner around the route until it returned to the hub. Once at the hub, all cargo was sorted according to final destination and placed in a waiting queue for the route to which the destination belonged. The next simulation day, new flights were generated, cargo from the waiting queues was loaded on the flights and the process started again.

Transit time for a shipment was determined by subtracting

the cargo's release time at the origination from its arrival time at its final destination. This transit time included these components:

--flight time - pre-computed and loaded into a data matrix for the entire network.

--transhipment time - the time interval between arrival and departure from the hub.

--handling time - a constant (one hour and thirty minutes) allowed at each base for cargo downloading, uploading, aircraft servicing, etc.

The simulation allowed for an originating shipment to be separated into two shipments in the event an aircraft arrived at a station but had only enough remaining capacity for part of the requirement from that station. In this event, each of these shipments was tracked individually until it reached its destination.

Cargo destined for a base that was down-route on the same petal was offloaded at that base and did not continue to the hub.

At the end of the simulated 90-day period, the transit times for all shipments were compiled. The program reported both a straight average transit time for all shipments and a weighted system transit time.

A weighted system transit time was computed manually for the LOGAIR system as it existed in the last quarter of FY 1979 (see Appendix E). Computation of actual system transit time and a single-hub based transit time provided a basis

of comparison for the two route structures. LOGAIR transit time, as it is currently reported, includes the elapsed time from the point when a package is made available for shipment to the time the aircraft arrives at the unloading facility at the destination base (4). Reported separately is the air terminal hold time report. This figure measures the elapsed time from when a package is made available for shipment until the aircraft departs the originating station (4). Therefore, by subtracting the average hold time from the average transit time, one can approximate the amount of flying time plus transhipment time and handling time for shipments between any two stations (4; 33). In this manner, a transit time was derived for the current system that was analogous to the simulation transit time.

Limitations and Assumptions of the Model. While every effort was made to make the simulation model reflect real world conditions, the incorporation of certain constraints was not feasible or practical for a computer simulation. These conditions included:

--individual base closing times/quiet hours were not considered. However, since practically all arrivals and departures at non-hub bases were between the hours of 0705 and 1600 local, individual base closing times and quiet hours do not significantly effect the itinerary as published (see Appendix C).

--aircraft diversions, including overflight of a base, flying a route in reverse, and diverting to a base not in the

route structure were not simulated. Circumstances requiring these actions in LOGAIR operations were too unique and infrequent to be practically simulated. However, LOGAIR contract managers make every effort to reschedule routes so that any airmiles and/or landings that may be lost to the contractor as a result of diversions are recouped before the end of the contract period. Therefore, total airmiles traveled and number of landings made by the end of the year would be approximately the same as was originally called for in the contract (8).

--LOGAIR policy is to connect all ALCs, HQ AFLC and APOEs with L-100 service and to restrict L-100 service from other stations when possible (32). In addition, there were numerous special requirements, such as L-100 service between TAC bases for the movement of F-15 engines. The simulation did provide L-100 service to all ALCs and Wright-Patterson AFB, but not to the APOEs. This was done to minimize the number of L-100s required in the network because they were the more expensive of the two types of aircraft to operate. However, L-100 #1 terminated at Tinker 1030L and would have been available for special requirements. Otherwise, the model provided daily service to all Air Force installations and weekday service to Key West and Jacksonville NASs as did the actual system.

To facilitate the operation of the model, certain assumptions were made:

--the average daily inbound and outbound cargo

requirements for a given station were generated based on the mean daily cargo weights plus or minus randomly generated variates.[11]

--It was assumed that Tinker AFB, OK was the location of the hub and had sufficient facilities to handle the required aircraft and cargo, and to download, sort, and load aircraft overnight for an 0600L launch. It is not the intent of this paper to justify the selection of Tinker as the system center, since it was the site which the Logistics Management Center considered a prime candidate for the hub (21). Neither is it within the scope of this project to argue the physical and technical feasibility of constructing a terminal with materiels handling equipment sufficient to accommodate the anticipated aircraft and cargo demands. As commercial firms have demonstrated, it is clearly possible to construct and operate such a facility (35:35).

--Contractors could provide sufficient aircraft (six L-100s and seventeen L-188s) to satisfy route structure demands. This assumption is totally feasible given the capacity of contract carriers in the continental United States today (3).

--An average of 1.5 hours stop-over at each base would be sufficient for cargo offloading/loading and aircraft servicing. This time compared favorably to the average 63 minute stop-over on the FY 79 LOGAIR itinerary. Additionally,

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[11]See Data Sources for mean weights explanation.

no individual stop extended beyond 90 minutes (23:7-8).

--All aircraft were "launched" simultaneously from the hub at 0600L.

--All cargo was "generated" instantly at the moment the "aircraft" arrived at a given base. This, again, was done to facilitate the simulation since an actual distribution of times that cargo was actually generated at each base could not be determined from available data. During the analysis, the real world transit times were adjusted by subtracting out average hold time so that the times for the two systems would be comparable.

Data Sources

Cargo Demand. Mean daily cargo weights were extracted from the Fiscal Year 80 cargo shipments table. This is a planning document compiled by the Directorate of Distribution, HQ AFLC, of the anticipated inbound and outbound cargo requirements for each LOGAIR base for the fiscal year. This table was used by AFLC/LOM during the manual construction of LOGAIR routes for the upcoming year (9). The table is a computer generated matrix showing origin/destination annual demands expressed in tons. This tonnage was divided by 365 to produce mean daily cargo weights.

Variability of Cargo Weights. To determine the nature of the distribution of individual cargo shipment weights, a computer listing of over 137,000 terminal IDCs (intransit data cards) was obtained from Sacramento Air Logistics

TABLE III

Average Daily Requirements in Tons

(24:1-8)

Station	Terminating	Originating
Tinker	38.19	24.40
Kelly	28.87	49.33
Little Rock	2.01	1.38
Barksdale	2.19	1.39
England	1.50	0.52
Blytheville	1.67	1.51
Robins	30.61	22.84
Eglin	2.70	1.23
MacDill	6.80	2.48
Key West	4.38	4.27
Homestead	3.76	4.77
Patrick	5.27	4.69
Jacksonville	2.69	4.46
Tyndall	4.10	0.88
Charleston	4.04	1.00
Shaw	2.46	2.68
Seymour-Johnson	4.65	1.92
Langley	3.15	1.50
Dover	12.51	23.57
McGuire	8.20	19.77
Pease	5.52	4.64
Loring	1.32	1.61
Plattsburgh	2.10	1.04
Griffiss	2.96	11.37
Wright-Patterson	14.4	15.79
Scott	1.94	0.30
Selfridge	0.91	0.46

TABLE III, continued

Station	Terminating	Originating
Wurtsmith	1.49	0.73
K.I. Sawyer	1.78	0.90
Duluth	0.95	0.57
Grand Forks	1.64	1.45
Minot	1.59	1.33
Offutt	2.10	0.69
Whiteman	1.91	1.15
Malmstrom	2.73	1.18
Ellsworth	2.32	1.95
F.E. Warren	1.23	0.75
Peterson	1.84	2.19
Cannon	1.83	1.18
Holloman	2.19	1.67
Kirtland	1.69	1.12
Davis-Monthan	3.22	1.72
Hill	21.50	28.55
Fairchild	1.32	0.76
McChord	8.52	5.38
Mountain Home	2.50	1.39
McClellan	18.57	37.35
Travis	12.71	1.28
Norton	11.50	6.90
Nellis	3.55	2.34
Luke	3.89	2.66
Columbus	1.65	0.89

Center/ACDBL. This listing represented all bases in the LOGAIR network. A random sample of 768 cargo weights was selected and processed through the Statistical Package for the Social

Sciences (SPSS). The SPSS "FREQUENCIES" routine was used to develop a probability distribution for the weight of cargo. The results of the "FREQUENCIES" run is contained in Appendix D. The frequency distribution was scaled by dividing it by its mean. The scaled figures were then used as input to the SIMSCRIPT routine for building the user-defined probability distributions.[12] When cargo was generated for any source-destination pair, a random variate was drawn from this user-defined probability distribution, and was multiplied by the mean daily demand for that source-destination pair.

Distance. Nautical miles were measured directly from a jet navigational chart (JNC).

Aircraft Capacity. Payload capacities of an L-188 and L-100 aircraft are 34,000 pounds and 46,100 pounds, respectively (23:iii-iv). The weight of pallets and nets was subtracted from these figures (two configurations are possible, so an average weight was taken). The resulting capacities used in the construction of the routes was 21.5 tons for the L-100 and 15.4 tons for the L-188.

System Transit Time (Actual). Transit time in hours between the stations of interest was extracted from the RCS HAF LET (M) 7106, Air Transportation Transit Report, furnished by HQ AFLC, Reports and Analysis Branch. LOGAIR shipments priority 1, 2, and 3 and their associated transit times were

[12] This user-defined probability function capability is described in SIMSCRIPT II.5 Programming Language (10:316-322).

taken for October, November, and December 1979 (25).

LOGAIR System Costs. Charges per L-100 nautical mile flown were $3.529, and per L-188 mile were $2.412 (28) based on figures contained in the FY 80 AFLC Logistical Airlift Briefing - LOGAIR, compiled by the Directorate of Distribution, HQ AFLC, LOGAIR and Requirements Branch. Cost per landing for both types of aircraft was $250 (28).

Terminal Hold Time (Actual). Hold time, in hours, of a shipment originating at a station bound for a particular base was extracted from the RCS HAF LET (M) 7107, Air Terminal Hold Time Report, furnished by HQ AFLC, Reports and Analysis Branch (26).

Relation to Research Questions

Research Question 1. Does a single-hub route structure yield lower transit times than the trunk-and-feeder system? To answer this question, a computer model was constructed to simulate single-hub performance. Flights and cargo demands for a 90-day period were generated, tracked, and recorded. Individual shipment transit times were weighted by tonnage and compiled into a separate figure. A sample of 60 bases was selected from the entire system to serve as a basis of comparison to the present system. Since the only data available on transit times are on those shipments which originate from the ALCs and Wright-Patterson AFB, the sample used for comparison included ten randomly selected bases served from each ALC and Wright-Patterson.

The total weighted system transit time generated by the simulation was then compared to the actual weighted system transit time computed manually from reported data.

Research Question 2. What will be the impact on contract direct operating costs of a single-hub route? To determine the change in operating costs, the total annual mileage of the single-hub route was determined and then multiplied by the contractural cost per mile charge related to each type of aircraft. The number of landings under the new route structure was multiplied by the contractural cost per landing, $250 (28). This charge was the same for both type aircraft. The 5 percent revenue charge was based on amount of cargo carried (28); this amount was the same for both route structures. Fuel costs above contract allowances varied directly with airmiles flown (28). Thus, the $2,463,000 charged under the former system was increased to $3,247,000 in accordance with the mileage difference between the two systems.

Research Question 3. If a single-hub system does produce faster transit times, to what degree will faster transit times lower inventory investment required to support the supply pipeline? To analyze this impact, data provided by the D041 model were utilized. D041, the Recoverable Consumption Item Requirements System, is a computerized system developed by HQ AFLC to substantiate the acquisition program, budget projections, and other logistics actions for recoverable consumption-type item replenishment spares (27:1-1). It receives input from many other AFLC data collection systems

(see Figure 5). Outputs from the Variable Safety Level (VSL) Subsystem were used to quantify the effect of a reduction of pipeline time on inventory requirements. Although the VSL Subsystem computation covers only a part of the supply system spectrum, the impact of one day's reduction in pipeline time has been quantified by a D041 run completed in June of 1977[13] (11).

Figure 5 represents the various factors involved in D041 computations. Although the VSL Subsystem is used mainly to calculate Safety Stock Levels, safety stock required is a function of, among other factors, order and ship time between depot and base. This relationship is demonstrated in Figure 6. The VSL computational formula below (30) demonstrates that an expedited transit time will have the effect of lowering overall stock requirements.

$$\text{Authorized Stock} = Q + \sqrt{3Q}$$

$$Q = D(PM + [1-P][T+H])$$

where

Q = Pipeline Requirement	P = Probability an item can be repaired at Base level
$\sqrt{3Q}$ = Safety Level	M = Base Repair Time
D = Daily Demand	T = Transit Time to and from the Depot
$1-P$ = Probability an item must be returned to a Depot for Repair	H = Handling Time

[13]According to AFLC/LOM, this is the last full run of the D041 program. Another run was planned for May 1980, but its results were unavailable at the time of final printing.

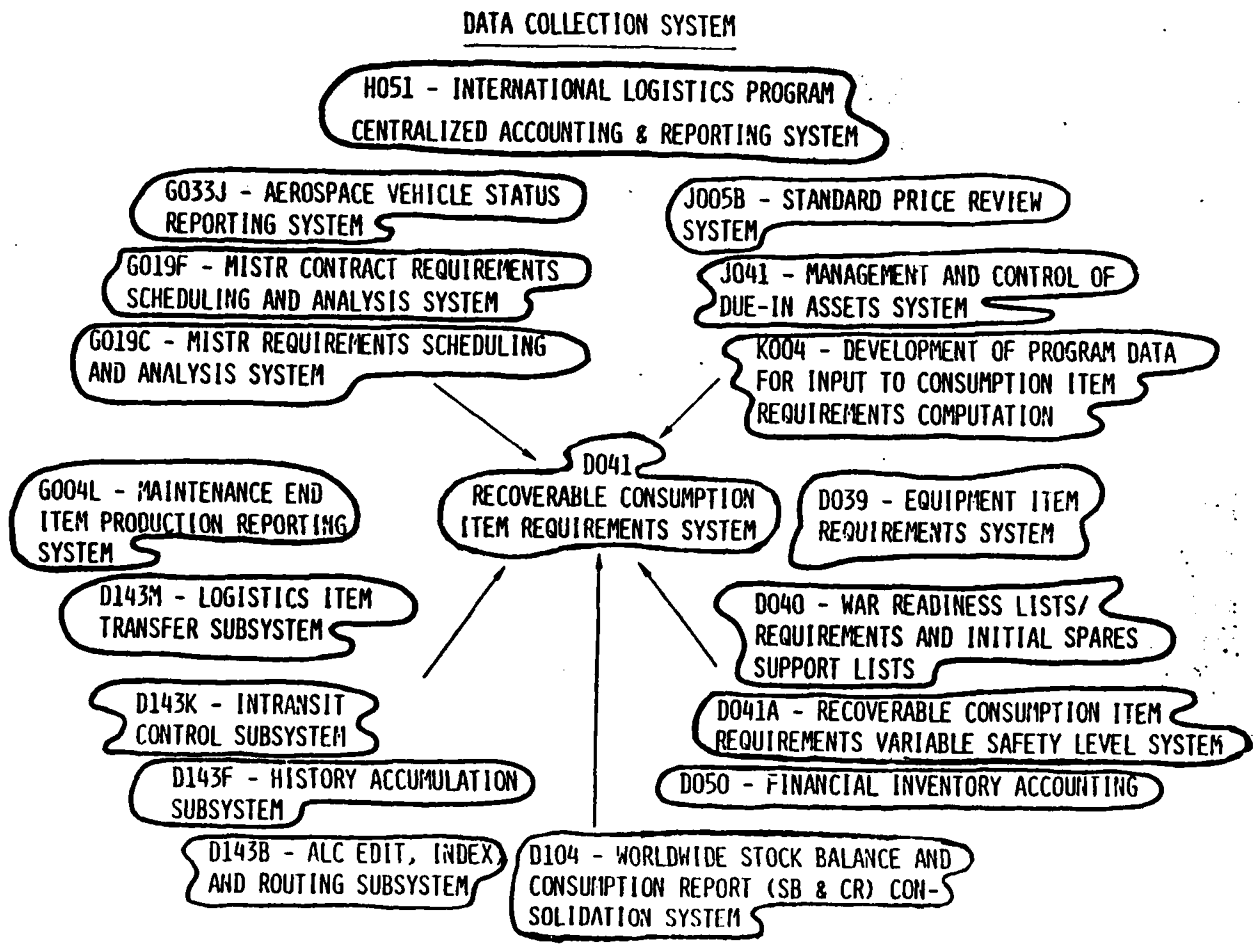

Figure 5

D041 Data Collection System

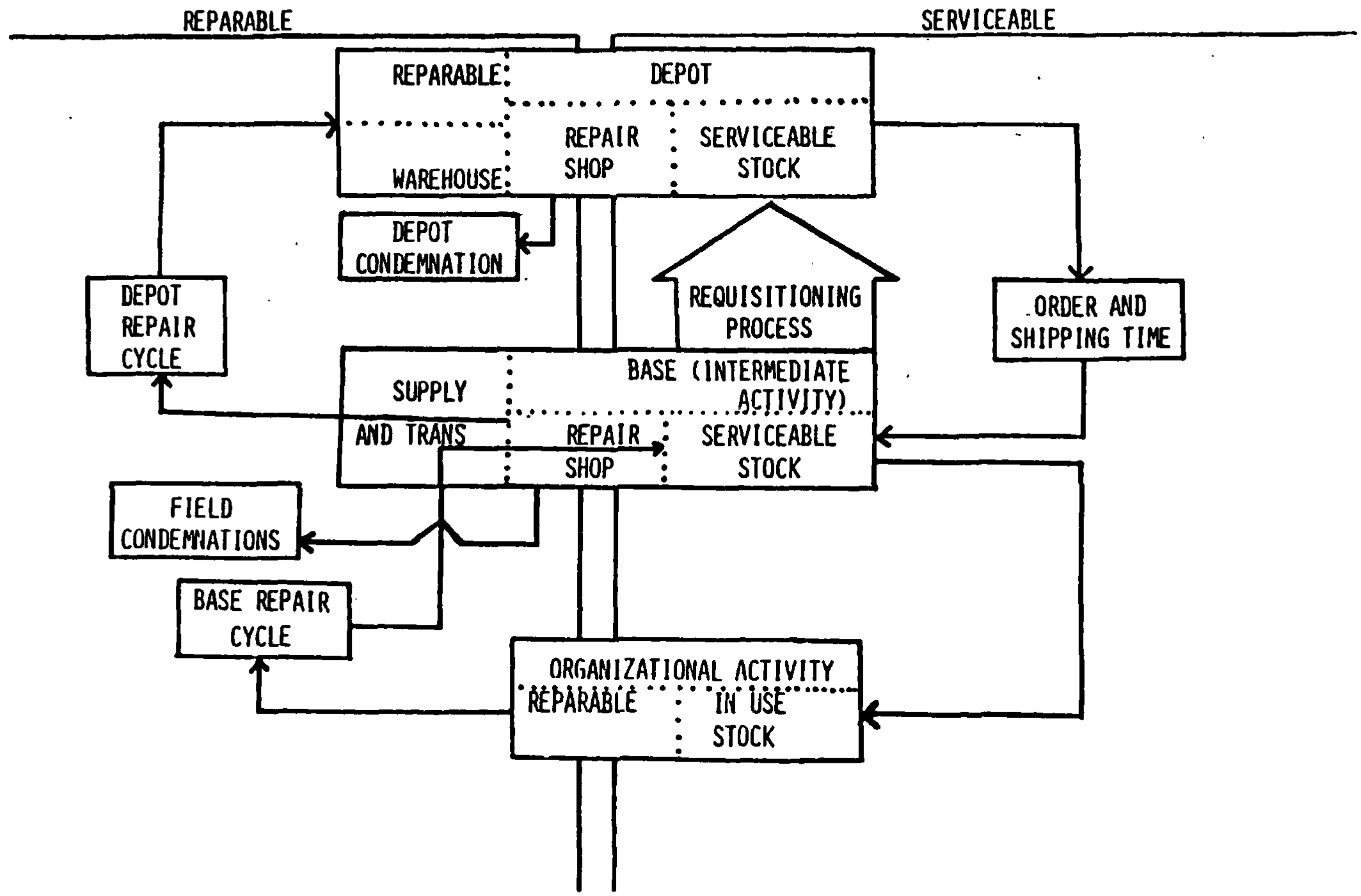

Figure 6

Air Force Implementation of VSL for Reparables

CHAPTER IV

RESULTS AND FINDINGS

This chapter details the results of this research effort and relates them to the research questions. Weighted transit time for the single-hub network was projected to be .22 days less than under the trunk-and-feeder system, permitting a $10.7 million reduction in inventory investment resulting from a faster supply pipeline. This savings was counter-balanced somewhat by a $9.35 million projected increase in LOGAIR direct operating costs.

Research Question 1

Can a single-hub network yield a lower overall transit time than the present network?

Transit time for the October-December 1979 time period was calculated for the 60 base-pairs in the sample by using data from the RCS LOG LET(M) 7106 and RCS LOG LET(M) 7107 reports. System transit time was estimated by multiplying the number of shipments transported between each sample base-pair by the average transit time (adjusted for hold time) for that base-pair, summing the product of number of shipments and average transit times for all base-pairs, and dividing by the total number of shipments for all base-pairs. Weighted system transit time was calculated in a similar manner. However, each base-pair's

average transit time (adjusted for hold time) and number of shipments product was multiplied by the total weight of all cargo shipped between the base-pair. The sum for all base-pairs was then divided by the product of the total weight of cargo for all base-pairs and the total number of shipments for all base-pairs (see Appendix E). Unweighted system transit time was found to be 1.36 days, and weighted system transit time was found to be 1.23 days. Unweighted system transit time represents the average time to ship anything between any two nodes in the system. Weighted system transit time, on the other hand, is a truer measure of the expected time to ship any item of cargo, because it is adjusted to reflect the fact that some links are used to transport far more freight than others.

The performance of the single-hub system was the major output of the simulation model. Although the simulation generated and tracked cargo for all possible base-pairs, the performance statistics were only collected for the 60 base-pairs in the sample. All cargo was tracked to insure that the cargo from the sample bases would experience the delays that would be expected in the full system. These delays would not have occurred in a system with only 60 possible source-destination combinations.[14] The same method of calculating

[14]Such delays would include a shipment having to wait at a base to be loaded on subsequent aircraft, if the next aircraft to arrive at that station is full. Shipment weights were generated stochastically to simulate the fact that, although on the average the demand on each route will be less

unweighted system transit time and weighted system transit time was used to make the simulation results directly comparable to the trunk-and-feeder system's results.

Unweighted system transit time and weighted system transit time for the single-hub system were projected to be 0.95 days and 1.01 days, respectively. The single-hub model demonstrated a 0.22-day decrease in weighted system transit time, and a 0.41-day decrease in unweighted system transit time over the trunk-and-feeder LOGAIR system. In addition, the single-hub system demonstrated extremely low variability in individual shipment transit times, as shown in Appendix G.

Conclusion: The single-hub network yielded transit times that were lower, on the average, than the trunk-and-feeder network.

Research Question 2

What is the impact of a single-hub system on LOGAIR contract direct operating costs?

Annual LOGAIR contract direct operating costs based on AFLC FY 80 projections are broken down as follows:

Landing Charges:	$30,587,000
L-100 Mileage Charges:	15,975,000
L-188 Mileage Charges:	20,213,000
Gasoline Surcharge:	2,463,000
Taxes:	1,335,000

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than the capacity of the airplane, on some days the aircraft may be fully loaded before it covered all bases on its route.

These figures were extracted from the FY 80 AFLC Logistical Airlift Briefing prepared by the LOGAIR Requirements Branch, HQ AFLC (28). Total operating costs for the year were $47,633,000.

For the single-hub system, miles flown by aircraft type was calculated by measuring the distance from an aeronautical jet navigation chart and multiplying mileage by the number of days in the year. Total annual distance for each type aircraft was then multiplied by the same mileage rates to arrive at mileage charges (see Appendix F). Total annual landings were determined by multiplying the number of daily landings by 365 and subtracting out the 208 landings saved by not serving Key West and Jacksonville NASs on weekends. Since taxes were based on cargo tonnage, they remained the same for both route configurations (28).

Gasoline surcharges were a function of miles flown. Single-hub surcharges were increased in the same proportion as mileage increased over the FY 80 system (28). The single-hub system's operating costs are summarized below:

Landing Charges:	$7,431,000
L-100 Mileage Charges:	12,422,000
L-188 Mileage Charges:	32,552,000
Gasoline Surcharge:	3,427,000
Taxes:	1,335,000

Conclusion: The single-hub system was projected to cost $56,987,000 per year. This is a projected increase of $9.35 million over the FY 80 trunk-and-feeder system.

Research Question 3

To what degree will faster transit times lower inventory investment required to support the supply pipeline?

Computations from HQ AFLC's D041A VSL system simulator were used as a conservative estimate of the incremental savings in inventory investment that would result from adopting the single-hub LOGAIR system. The D041 system is extremely complex and cumbersome. It requires too many hours of computer time to be used routinely as a "what if" forecasting tool (11). For this reason, the last available "what if" projection, run by HQ AFLC/LOR in June 1977, was used as a baseline. The June 1977 VSL run was used to investigate the expected savings from a one-day decrease in the logistics transportation pipeline. Total savings was projected to be $69.6 million in 1977 dollars (11). According to the Chief of the Requirements Analysis Branch, HQ AFLC/LORRA, a one-day reduction in LOGAIR transit time would account for 70 percent of the dollars saved, which is approximately $48.7 million (11). HQ AFLC's Requirements Analysis Branch (22) stated the $48.7 million figure was a conservative estimate of incremental savings in inventory investment that could have been experienced in 1979 from a one-day decrease in pipeline time. This was because the cost to buy spares increased greatly between 1977 and the time this study was conducted (22).

Multiplying the $48.7 million/day figure by the 0.22 days saved by implementing the single-hub system yielded a projected inventory investment savings of approximately

$10.7 million.

Conclusion: A conservative estimate of the change in inventory investiment resulting from implementing the single-hub system indicated a projected savings of $10.7 million.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

This chapter presents the research team's conclusions based on the results of this study, recommendations for LOGAIR managers at HQ AFLC, and recommendations for future research in this area.

Conclusions

This study has shown that, had the single-hub system been in operation in October, November, and December 1979, transit time for shipments moved by LOGAIR could have been reduced by 0.22 days, with less variability in transit times. This reduction in transit time would have been accompanied by a $9.35 million annual increase in operating costs. The increase in operating costs would have been outweighed, however, by the decrease in inventory investment costs, which were conservatively estimated at $10.7 million. Therefore, the net savings from operating a single-hub system in 1979 could have been at least $1.35 million.

Limitations of the Study

The costs and benefits outlined above can in no way be construed as all-inclusive. Although this study only addressed operating costs and inventory investment savings, the researchers recognize that other factors would have to be

considered before a decision to adopt a single-hub system could be made. Some of these factors include: the cost of expanding facilities and adding additional materiel handling equipment at Tinker AFB; savings from reducing materiel handling requirements at the other ALCs, APOEs and HQ AFLC, since those bases would no longer be required to tranship cargo; changes in manpower requirements throughout the system; possible increases in contract charges to compensate the contractors for the additional overhead for operating 23 aircraft instead of 15; and savings due to economies of scale associated with performing all sorting and transhipping at Tinker. In addition, this study made no attempt to quantify the benefits of increased readiness resulting from reducing both pipeline time and the variability of pipeline time. The areas addressed, however, clearly indicate that the single-hub system is promising from both cost and readiness standpoints, and merits further examination.

Recommendations for AFLC

In order to more completely evaluate the total costs of the single-hub system, at least two cost areas must be investigated further: funding required to upgrade and enlarge facilities at Tinker AFB, plus associated manpower requirements; and any possible reductions in operating costs at the other ALCs and APOEs.

In addition, HQ AFLC should attempt to investigate, quantify, and publicize the implications of increases or

decreases in LOGAIR service on readiness USAF-wide.

Recommendations for Future Study

During the course of this study, the researchers identified several areas associated with the single-hub model that require further study. These areas include:

--Revision of the simulation model to include more "real world" requirements such as diversion of aircraft, L-100 support for major readiness exercises, and service to bases not in the route structure. This study was unable to address many of these areas in the time allotted.

--Investigation using Kelly AFB, Texas as the hub. Kelly is the single largest generator of cargo in the system. It seems logical that some reduction in weighted transit time would result from being able to ship Kelly's outbound requirements directly without having to tranship to Tinker.

--Simulation of reduced service to small users (e.g. 5 or 6 days a week). Investigate various levels of service to determine if operating costs can be reduced without significantly increasing weighted transit time. Several of the smaller user bases did not generate cargo every day. Intuitively, it seems that if these bases were served less frequently than daily, contract costs could be reduced without significantly increasing system transit time.

--Review of scheduling and other operating practices of commercial air package express carriers to see if their methods could be applied to LOGAIR and what benefit, if any, could be

gained by doing so.

--Investigation of ways to reduce hold time at the ALCs (e.g. improved materiels handling policies/practices, greater management emphasis on expediting shipments). For four of the five ALCs, average hold time exceeded 21 hours (see Appendix E).

Summary of Research

As demonstrated by the results presented above, a single-hub LOGAIR system can reduce system transit time over the trunk-and-feeder line system. Increases in operating costs of the single-hub system can be more than countered by savings in inventory investment costs. The single-hub system holds great promise and merits further investigation.

APPENDIX A

RAY-SWEEP, ROUTE GENERATOR PROGRAM

```
$       OPTION   FORTRAN,MAP,SYMREF
$       FORTY    NFORM,NLNO,DEBUG,XREF
$       LIMITS   .27K
 DIMENSION IKEY(60),IFNLROUT(110)
 REAL ANGLE(60,60)
 CHARACTER RECORD1*1(448),RECORD*448
 EQUIVALENCE (RECORD1,RECORD)
 LOGICAL SWITCH,MEMBER,IMPRVFLG,DEPOTFLG
 INTEGER UNION,TOURS,TOUR,GRANTOUR,HUB,SETHEAD,ACFTYPE
 REAL CARGO/0.00/,MICAPCNT/.70/,L188LOAD/14.5/,L100LOAD/23.0/,HNDLTIME
&/1.5/
 COMMON/TOTALS/QDISTOTL,ROUTOTAL/PETALS/GRANTOUR(20,25),NUMPETAL
 COMMON/ROUTES/KOUNT,TOURS(12,20),TOUR(15)/MATRIX/DISTANCE(60,60),
&BASES(10,60)/SETHD/SETHEAD/AFLCIO/UNION(60,60)
 COMMON/TRUTHTBL/MEMBER,SWITCH/LOAD/CAPACITY/SORTSTUF/SWEEPANG(60)
&,KEYS(60)
C INPUT ROUTINE
 READ,NUMBASES,HUB,AIRSPEED
 READ(05,66,END=88)((BASES(IN,JN),IN=1,NUMBASES),JN=1,5)
 66 FORMAT(V)
 88 PRINT,"IN  ",IN,"JN  ",JN
 DO 100 I=1,NUMBASES
  DO 100 J=1,NUMBASES
 X=BASES(I,2)-BASES(J,2)
 Y=BASES(I,3)-BASES(J,3)
 X=X*60
 Y=Y*60
 DISTANCE(I,J)=SQRT(X**2+Y**2)/AIRSPEED
 IF(X.EQ.0)GO TO 110
 121 ANGLE(I,J)=ATAN(Y/X)
 IF (X.LT.0) ANGLE(I,J)=ANGLE(I,J)+180
 IF (ANGLE(I,J).LT.0) ANGLE(I,J)=ANGLE(I,J)+360.00
 GO TO 100
 110 ANGLE(I,J)=90.00
 IF(Y.LT.0)ANGLE(I,J)=270.00
 IF(Y.EQ.0)ANGLE(I,J)=0.00
 100 CONTINUE
C SAVE ANGLES FROM HUB TO BASES, PREPARE TO SORT THEM
 DO 130 I=1,NUMBASES
 IF(I.EQ.HUB) GO TO 130
 SWEEPANG(I)=ANGLE(I,HUB)
 KEYS(I)=I
 130 CONTINUE
 CALL SORTKEYS(NUMBASES-1)
 PRINT,"BASES IN POLAR COORD ORDER"
 PRINT,(KEYS(JJJJ),JJJJ=1,NUMBASES)
C ANGLE FROM HUB TO HUB MUST BE EXCLUDED
 KMOS=1
 135 DO 140 MOSTOURS=1,NUMBASES
C BEGIN GENERATING INITIAL TOURS
 NUMTOURS=1
 NUMPETAL=0
 J=0
 150 TOUR(1)=HUB
```

```
 I=1
 CARGO=0.0
 TOURLGTH=DISTANCE(HUB,KEYS(J+1))
 ACFTYPE=188
 CAPACITY=L188LOAD
C IF CONSTRAINTS ARE EXCEEDED, DONT ADD ANYMORE BASES
C CHECK DISTANCE,AIRCRAFT CAPACITY CONSTRAINTS
C TIME CONSTRAINTS TO BE ADDED LATER
 160 IF(CARGO+BASES(KEYS(J+1),5)-BASES(KEYS(J+1),4).GT.
&MICAPCNT*CAPACITY) GO TO 170
 IF(J.LT.1)GO TO 167
 TTT=(TOURLGTH+DISTANCE(KEYS(J),KEYS(J+1)))+
&((DISTANCE(HUB,KEYS(J+1))+DISTANCE(HUB,TOUR(1)))+
&HNDLTIME*(I+1))
 IF(TTT.GE.16)GO TO 170
 TOURLGTH=TOURLGTH+DISTANCE(KEYS(J),KEYS(J+1))+DISTANCE(KEYS(J+1),HUB)
 167 I=I+1
 CARGO=CARGO+BASES(KEYS(J+1),5)-BASES(KEYS(J+1),4)
 TOUR(I)=KEYS(J+1)
 IF(J+1.GT.NUMBASES)GO TO 180
 J=J+1
 GO TO 160
 180 IMPRVFLG=.T.
 170 IF (I.GE.4)CALL LINSTSP(I,ACFTYPE)
 PRINT,"TOUT LENGTH--",TTT."  CARGO--",CARGO
 PRINT,"NUMBER OF PETALS-- ",NUMPETAL
 PRINT,"NUMBER OF BASES USED--",J " BASES IN THIS PETAL--",I
 IF (I.GT.1) GO TO 190
 TOUR(2)=KEYS(J+1)
 DEPOTFLG=.T.
 ACFTYPE=100
 I=2
 190 CALL BLDRTES(I,ACFTYPE)
 IF(.NOT.DEPOTFLG)GO TO 195
 DEPOTFLG=.F.
 TOUR(1)=HUB
 J=J+1
 TOUR(2)=KEYS(J)
 I=2
 CARGO=BASES(KEYS(J).5)-BASES(KEYS(J),4)-L100LOAD
 IF(CARGO.LT.0)CARGO=0
 GO TO 160
 195 IF(J+1.GT.NUMBASES)IMPRVFLG=.T.
 IF(IMPRVFLG) GO TO 200
 GO TO 150
C CONTINUE STATEMENT BELOW USED AS A PLACE MARK
 200 CONTINUE
   CALL SINGLE(HUB)
   CALL DOUBLE(HUB)
C SINGLE AND DOUBLE ARE IMPROVEMENT ROUTINES BASED
C ON THE ROUTINES SUGGESTED BY ELIO CUNTO (OPS
C RSCH, VOL 26, PP 183-196), BUT USING THE SAVINGS
C APPROACH SUGGESTED BY B.L. GOLDEN (NETWORKS,VOL 7
C , PP 113-148).
```

```
C BOTH ROUTINES SEEK TO REDUCE TOTAL DISTANCE TRAVELED
C FOR ALL ROUTES BY INSERTING BASES FROM ONE ROUTE
C INTO ANOTHER ROUTE. SINGLE CONSIDERS BASES ONE AT
C A TIME, DOUBLE, TWO AT A TIME
C
C PRINT AND RECORD IMPPOVED ROUTE
C
 WRITE(06,2)
 2 FORMAT(5X "ROUTE",4X,"DISTANCE",4X,"# OF BASES",4X."BASES")
 DO 210 IRT=1,NUMPETAL
 WRITE(06.3)GRANTOUR(IRT,1).GRANTOUR(IRT,3).GRANTOUR(IRT,2),
&(GRANTOUR(IRT,IIR+4),IIR=1,GRANTOUR(IRT.2))
 3 FORMAT(7X,I2,7X,I5,8X.20(I2,3X))
 210 CONTINUE
C
C OUTPUT ROUTINE
C CLEAR OUTPUT BUFFER CALLED RECORD
 DO 220 IC=1.448
 220 RECORD1(IC)="0"
C BUILD A SINGLE RECORD FOR THE ENTIRE ROUTE STRUCTURE
 ENCODE (RECORD,11)MOSTOURS,ROUTOTAL,((GRANTOUR(IX,JX),JX=1,GRANTOUR
&(IX.2)).IX=1,NUMPETAL)
 11 FORMAT(I2,I6.110(I4))
C WRITE THE RECORD TO A DISK FILE
 WRITE(12,12)RECORD
 12 FORMAT(A448)
C ROTATE THE ANGLE MATRIX
 TEMPO=SWEEPANG(1)
 ITEMPO=KEYS(1)
 DO 230 IIII=1,NUMBASES
 SWEEPANG(IIII)=SWEEPANG(IIII+1)
 230 KEYS(IIII)=KEYS(IIII+1)
 SWEEPANG(60)=TEMPO
 KEYS(60)=ITEMPO
 140 CONTINUE
 IF(KMOS.LT.1)GO TO 148
 KMOS=0
 KKK=NUMBASES+1
 DO 145 IIII=1,NUMBASES
 145 IKEY(KKK-IIII)=KEYS(IIII)
 DO 146 IIII=1,NUMBASES
 146 KEYS(IIII)=IKEY(IIII)
 GO TO 135
 148 REWIND 12
 THISTOTL=999999
 250 READ(12,13,END=290)IROUTE,IDIST,(IFNLROUT(IY),IY=1,110)
 13 FORMAT(I2,I6,110(I4))
 IF(IDIST.GT.THISTOTL)GO TO 240
 I=1
 J=1
 K=1
 270 L=K+1
 M=IFNLROUT(L)
 280 IF (2+L+M.EQ.K)GO TO 260
```

```
 GRANTOUR(I,J)=IFNLPOUT(K)
 J=J+1
 K=K+1
 IF(K.GT.110)GO TO 235
 GO TO 280
 260 I=I+1
 J=1
 GO TO 270
 235 TDISTOTL=IDIST
 240 GO TO 250
 290 DO 300 N=1,I
 WRITE(06,4)
 4 FORMAT(2X,"RTE",3X,"NOF",4X,"DIST",2X,"ACFT")
 WRITE(06,5)
 5 FORMAT(2X,"NO.",2X,"BASES",3X,"ANCE",2X,"TYPE",4X,"BASES")
 DO 300 NN=1, GRANTOUR(N,2)
 300 WRITE(06,15)I, BASES(GRANTOUR(N,NN),1)
 15 FORMAT(3X,I2,4X,I2,3X,I6,3X,I3,16(3X,I2))
 STOP
 END
 SUBROUTINE LINSTSP(N,ACFTYPE)
 LOGICAL SWITCH,MEMBER
 INTEGER UNION,TOURS,TOUR,GRANTOUR,HUB,SETHEAD,ACFTYPE
 COMMON/TOTALS/QDISTOTL,ROUTOTAL/PETALS/GRANTOUR(20,25),NUMPETAL
 COMMON/ROUTES/KOUNT,TOURS(12,20),TOUR(15)/MATRIX/DISTANCE(60,60),
&BASES(10,60)/SETHD/SETHEAD/AFLCIO/UNION(60,60)
 COMMON/TRUTHTBL/MEMBER,SWITCH/LOAD/CAPACITY/SORTSTUF/SWEEPANG(60)
&,KEYS(60)


C TRAVELING SALESMAN ROUTINE CALCULATES
C THE SHORTEST ROUTE BETWEEN BASES IN A
C PETAL USING SHEN LIN'S ALGORITHM (BELL
C TECH JNL, VOL. 44, P2245)
C FIRST, CALCULATE LENGTH OF THE INITIAL TOUR
   CALL TOTALGTH(N,TOUR)
 KOUNT=0
C RECORD INITIAL TOUR
   CALL RCDROUTE(TOUR,DISTOTL,1,N,ACFTYPE)
   CALL CLEAR(N)
C CLEAR INITIALIZES UNION, AN ARRAY CONTAINING
C THE SET OF ALL BASE LINKS THAT HAVE BEEN USED
C IN LOCALLY OPTIMAL SOLUTIONS, TO ZEROES.
C N IS THE NUMBER OF BASES IN THIS PETAL.
C
C CALCULATE R, THE NUMBER OF LOCALLY OPTIMAL
C TOURS TO BE GENERATED TO OBTAIN A .99
C PROBABILITY THAT A GLOBAL OPTIMUM IS AMONG THEM
CR=INT(ALOG10(.01)/ALOG10(1-2**(-N/10)))
 R=16
 PRINT,"BASES THIS PETAL-- ",N
C
C BEGIN MAIN LOOP
 DO 310 M=1,R
```

```
C NOTE THAT EACH OF THE R TOURS USES IT'S
C PREDECESSOR AS A START POINT, THEREFORE,
C THE ALGORITHM CONVERGES ON AN OPTIMUM.
 IF (M.GT.1) Q=1
 320 COUNT=1
 330 IF (COUNT.GE.N+1)GO TO 360
 IF (Q.LT.1) GO TO 340
   CALL SETCHK(N)
C SETCHK CHECKS IF A LINK FROM HUB TO THE
C LAST BASE HAS BEEN INCLUDED IN A LOCALLY OPTIMAL TOUR
 IF (MEMBER) GO TO 370
 340 CALL IMPROVE(N)
C IMPROVE ATTEMPTS TO IMPROVE TOUR BY
C SYSTEMATICALLY REPLACING 3 LINKS WITH
C 3 OTHER LINKS. IT CALLS SWAPLINK TO CHANGE
C THE TOUR IF IMPROVEMENT CAN BE MADE
 IF(SWITCH) GO TO 320
C ROTATE CITIES IN TOUR AND TRY TO IMPROVE AGAIN
 370 ITOUR=TOUR(1)
 DO 380 IDX=1,N-1
 380 TOUR(IDX)=TOUR(IDX+1)
 TOUR(N)=ITOUR
C IF LINK BETWEEN BASE 1 AND BASE N IS IN
C A LOCAL OPTIMUM, DELAY IMPROVEMENT
   CALL SETCHK(N)
 IF (MEMBER) GO TO 360
 COUNT=COUNT+1
 GO TO 330
C IF 380 WASN'T THE FIRST PASS, IMPROVE AGAIN ANYWAY.
 360 IF(Q.LT.1) GO TO 400
 Q=0
 GO TO 320
C ADD THE LINKS IN THE ROUTE TO THE SET OF USED LINKS
 400 CALL TAGLINKS(N)
C RECORD THIS LOCAL OPTIMUM AND START
C SEARCHUING FOR ANOTHER.
   CALL TOTALGTH(N,TOUR)
   CALL RCDROUTE(TOUR,DISTOTL,R,N,ACFTYPE)
 310 CONTINUE
C SORT TOURS IN ASCENDING ORDER BY DISTANCE
   CALL SORTOURS
 RETURN
C END OF TSP SUBROUTINE
 END
 SUBROUTINE TOTALGTH(NUMBASES,QTOUR)
 INTEGER QTOUR(NUMBASES)
 COMMON/TOTALS/QDISTOTL
 COMMON/MATRIX/DISTANCE(60,60)
 DO 10 I=1,NUMBASES-1
 10 QDISTOTL=QDISTOTL+DISTANCE(QTOUR(I),QTOUR(I+1))
 QDISTOTL=QDISTOTL+DISTANCE(QTOUR(NUMBASES),QTOUR(1))
 RETURN
 END
 SUBROUTINE RCDROUTE(VECTOR,LONG,NUMBER,HOWMANY,AIRPLANE)
```

```
 IMPLICIT INTEGER (C)
 INTEGER TOURS,HOWMANY,VECTOR(HOWMANY),AIRPLANE
 REAL LONG
 COMMON/ROUTES/COUNT,TOURS(12,20)
 COUNT=COUNT+1
 PRINT,"ENTERING RCDROUTE. COUNT=",COUNT
 TOURS(COUNT,1)=LONG
 IF(NUMBER-COUNT)410,420,430
 420 TOURS(COUNT,2)=99999
 TOURS(COUNT,3)=COUNT-1
 GO TO 460
 430 TOURS(COUNT,2)=COUNT+1
 TOURS(COUNT,3)=COUNT-1
 GO TO 460
 410 WRITE(06)  "ERROR IN RCDROUTE ****** TERMINATING"
 STOP
 460 DO 130 I=1, HOWMANY
 130 TOURS(COUNT,I+4)=VECTOR(I)
 TOURS(COUNT,4)=AIRPLANE
 RETURN
 END
C
 SUBROUTINE CLEAR(INDX)
 INTEGER SET(60,60)
 COMMON/AFLCIO/SET
C NOTE THAT SET IS COMMON WITH UNION
 DO  10 I=1,INDX
  DO 10 J=1,INDX
 10 SET(I,J)=0
 RETURN
 END
 SUBROUTINE SETCHK(I)
 LOGICAL MEMBER
 INTEGER UNION,TOUR,TOURS
 COMMON/AFLCIO/UNION(60,60)/TRUTHTEL/MEMBER
 COMMON/ROUTES/KOUNT,TOURS(12,20),TOUR(15)
 IF (UNION(TOUR(1),TOUR(I)).EQ.0)GO TO 10
 MEMBER=.T.
 RETURN
 10 MEMBER=.F.
 RETURN
 END
C
C FOR ALPHA TRUE = 18, FALSE = 16
 SUBROUTINE IMPROVE(NN)
 INTEGER NN,TOUR,TOURS
 LOGICAL SWITCH,MEMBER,ALPHA
 COMMON/ROUTES/KOUNT,TOURS(12,20),TOUR(15)/TRUTHTEL/MEMBER,SWITCH
 COMMON/MATRIX/DISTANCE(60,60),BASES(10,60)
 ALPHA=.F.
 SWITCH=.F.
 DO 470 K=1,NN-3
  DO 470 J=K+1,NN-1
 D1=DISTANCE(TOUR(K),TOUR(J+1))+DISTANCE(TOUR(1),TOUR(J))
```

```
D2=DISTANCE(TOUR(1),TOUR(J+1))+DISTANCE(TOUR(K),TOUR(J))
IF (D1.LE.D2) GO TO 480
D=D2
ALPHA=.T.
GO TO 490
480 D=D1
ALPHA=.F.
490 D=D+DISTANCE(TOUR(K+1),TOUR(NN))
D3=DISTANCE(TOUR(1),TOUR(NN))+DISTANCE(TOUR(K),TOUR(K+1))
&+DISTANCE(TOUR(J),TOUR(J+1))
IF(D.LT.D3)GO TO 500
470 CONTINUE
RETURN
500 CALL SWAPLINK(ALPHA,J,K,NN)
SWITCH=.T.
RETURN
END
SUBROUTINE SWAPLINK(BOOLEAN,JJ,KK,NNN)
INTEGER TNDX/1/,TSTAR(15),TOURS,TOUR
LOGICAL BOOLEAN
COMMON/ROUTES/KOUNT,TOURS(12,20),TOUR(15)
DO 10 NDX=JJ+2,NNN
TSTAR(TNDX)=TOUR(NDX)
10 TNDX=TNDX+1
DO 12 NDX=KK+1,JJ
TSTAR(TNDX)=TOUR(NDX)
12 TNDX=TNDX+1
IF (BOOLEAN) GO TO 18
DO 14 NDX=1,KK
TSTAR(TNDX)=TOUR(NDX)
14 TNDX=TNDX+1
GO TO 20
18 NDXZ=0
DO 19 NDX=NDXZ,KK-1
TSTAR(TNDX)=TOUR(KK-NDX)
19 TNDX=TNDX+1
20 DO 21 NDX=1,NNN
21 TOUR(NDX)=TSTAR(NDX)
RETURN
END
SUBROUTINE TAGLINKS(N)
INTEGER UNION,TOUR,TOURS
COMMON/AFLCIO/UNION(60,60)/ROUTES/KOUNT,TOURS(12,20),TOUR(15)
DO 510 I=1,N-1
510 UNION(TOUR(I),TOUR(I+1))=1
UNION(TOUR(N),TOUR(1))=1
RETURN
END
SUBROUTINE SORTOURS
LOGICAL XCHG,SWAP
INTEGER SETHEAD,SUCC/2/,PRED/3/,D/1/,SETHEAD,TOURS
COMMON/ROUTES/KOUNT,TOURS(12,20)/SETHD/SETHEAD
C SORT TOURS MARTIX IN ASCENDING ORDER BY DISTANCE
SETHEAD=1
```

```
520 IDX=1
XCHG=.F.
530 SWAP=.F.
IF(TOURS(IDX,SUCC).GT.KOUNT)GO TO 540
IF(TOURS(TOURS(IDX,SUCC),D).GE.TOURS(IDX,D))GO TO 540
T=TOURS(IDX,PRED)
IF(T.LE.00000)SETHEAD=TOURS(IDX,SUCC)
TOURS(TOURS(IDX SUCC),PRED)=TOURS(IDX,PRED)
TOURS(IDX,PRED)=TOURS(IDX,SUCC)
TT=TOURS(TOURS(IDX,SUCC),SUCC)
TOURS(TOURS(IDX,SUCC),SUCC)=IDX
TOURS(IDX.SUCC)=TT
IF(TT.LT.99999)TOURS(TT,PRED)=IDX
IF(T.GT.00000)TOURS(T,SUCC)=TOURS(IDX,PRED)
SWAP=.T.
XCHG=.T.
IF(TOURS(IDX,SUCC).LE.KOUNT)GO TO 530
540 IDX=TOURS(IDX,SUCC)
IF(IDX.LT.KOUNT)GO TO 530
IF(XCHG)GO TO 520
RETURN
END
C
SUBROUTINE SORTKEYS(NUMBASES)
COMMON/SORTSTUF/SWEEPANG(60),KEYS(60)
M=NUMBASES
580 IF(M.LE.1)GO TO 590
M=INT(M/2)
J=1
550 K=J
560 IF(SWEEPANG(K+M).GE.SWEEPANG(K))GO TO 570
TEMP=SWEEPANG(K)
ITEMP=KEYS(K)
SWEEPANG(K)=SWEEPANG(K+M)
KEYS(K)=KEYS(K+M)
SWEEPANG(K+M)=TEMP
KEYS(K+M)=ITEMP
K=K-M
IF(K.GT.1)GO TO 560
570 J=J+1
IF(J.LE.NUMBASES-M)GO TO 550
GO TO 580
590 RETURN
END
SUBROUTINE BLDRTES(IDX,ACFTYPE)
INTEGER TOURS,TOUR,GRANTOUR,SETHEAD
COMMON/ROUTES/KOUNT,TOURS(12,20),TOUR(15)/PETALS/GRANTOUR(20,25),
&NUMPETAL/SETHD/SETHEAD/TOTALS/QDISTOTL,ROUTOTAL
NUMPETAL=NUMPETAL+1
GRANTOUR(NUMPETAL,1)=NUMPETAL
GRANTOUR(NUMPETAL,4)=ACFTYPE
GRANTOUR(NUMPETAL,2)=IDX
IF(IDX.GE.4)GO TO 10
CALL TOTALGTH(IDX,TOUR)
```

```
 GRANTOUR(NUMPETAL,3)=QDISTOTL
 DO 9 I=1,IDX
 9 GRANTOUR(NUMPETAL,I+4)=TOUR(I)
 GO TO 15
 10 GRANTOUR(NUMPETAL,3)=TOURS(SETHEAD,1)
 DO 12 I=1,IDX
 12 GRANTOUR(NUMPETAL,I+4)=TOURS(SETHEAD,I+4)
 15 ROUTOTAL=ROUTOTAL+GRANTOUR(NUMPETAL,3)
 RETURN
 END
 SUBROUTINE SINGLE(HUB,ACFTYPE)
 REAL MSAVINGS,CAPACITY
 INTEGER HUB,ACFTYPE,TOURS,TOUR,NTOUR(20),SETHEAD,GRANTOUR
 LOGICAL IDIDTHIS/.F./
 COMMON/PETALS/GRANTOUR(20,25),NUMPETAL/TOTALS/QDISTOTL,ROUTOTAL
 COMMON/SETHD/SETHEAD/ROUTES/KOUNT,TOURS(12,20),TOUR(15)/MATRIX/
&DISTANCE(60,60),BASES(10,60)
 COMMON/LOAD/CAPACITY
 DO 600 K=1,NUMPETAL
 KMINUS=K-1
 IF(K.EQ.1)KMINUS=NUMPETAL
 KPLUS=K+1
 IF(K.EQ.NUMPETAL)KPLUS=1
 DO 610 J=1,GRANTOUR(K,2)
 IF(GRANTOUR(K,2)-J)420,420,430
 420 JPLUS=4
 GO TO 350
C J+4=J+1+3; I.E. -- THE OFFSET IN GRANTOUR
 430 JPLUS=J+4
 350 IF (J-1)450,450,440
 450 JMINUS=GRANTOUR(K,2)+3
 GO TO 3602
C J+2=J-1+3; I.E. -- THE NEGATIVE OFFSET IN GRANTOUR
 440 JMINUS=J+2
 3602 IF(GRANTOUR(K,J+4).EQ.HUB) GO TO 610
 SAVINGS=DISTANCE(GRANTOUR(K,JPLUS),GRANTOUR(K,JMINUS))-
&(DISTANCE(GRANTOUR(K,J+4),GRANTOUR(K,JPLUS))+DISTANCE(GRANTOUR(K,J+4),
&GRANTOUR(K,JMINUS)))
 KVAR=KPLUS
 620 OLENGTH=GRANTOUR(KVAR,3)
 DO 630 I=1,GRANTOUR(KVAR,2)
 630 TOUR(I+1)=GRANTOUR(KVAR,I+3)
 TOUR(1)=GRANTOUR(K,J+4)
 IF(GRANTOUR(KVAR,2).LE.2)GO TO 650
 CALL LINSTSP(GRANTOUR(KVAR,2)+1,ACFTYPE)
 660 IF (IDIDTHIS)GO TO 670
 DO 680 L=1,GRANTOUR(KVAR,2)+1
 680 NTOUR(L)=TOURS(SETHEAD,L+4)
 670 THISLGTH=TOURS(SETHEAD,1)
 GO TO 690
 650 CALL TOTALGTH(GRANTOUR(KVAR,2)+1,TOUR)
 THISLGTH=QDISTOTL
 DO 390 L=1,GRANTOUR(KVAR,2)+1
 390 NTOUR(L)=TOUR(L)
```

```
 690 IF(IDIDTHIS)GO TO 700
 PSAVINGS=SAVINGS-(OLENGTH-THISLGTH)
 KVAR=KMINUS
 IDIDTHIS=.T.
 GO TO 620
 700 IDIDTHIS=.F.
 MSAVINGS=SAVINGS-OLENGTH+THISLGTH
 IF(PSAVINGS.GT.MSAVINGS)PSAVINGS=MSAVINGS
 IF(PSAVINGS.GT.0.00)GO TO 610
 IF(PSAVINGS-MSAVINGS)720,740,740
 720 KVAR=KPLUS
 DO 710 L=1,GRANTOUR(KVAR,2)+1
 710 CARGOES=CARGOES+BASES(NTOUR(L),5)-BASES(NTOUR(L),4)
C CHECK IF ADDING BASE J TO K+1 WILL EXCEED ACFT CAPACITY
 IF(CARGOES.GT.CAPACITY)GO TO 610
C ADD BASE J TO ROUTE K+1
 DO 750 L=1,GRANTOUR(KVAR,2)+1
 750 GRANTOUR(KVAR,L+4)=NTOUR(L)
C UPDATE THE NUMBER OF BASES IN ROUTE K+1
 GRANTOUR(KVAR,2)=GRANTOUR(KVAR,2)+1
 GO TO 760
 740
 740 DO 730 L=1,GRANTOUR(KVAR,2)+1
 730 CARGOES=CARGOES+BASES(TOURS(SETHEAD,L+4),5)-BASES(TOURS(SETHEAD,
&L+4),4)
C CHECK IF ADDING BASE J TO ROUTE K-1 WILL EXCEED ACFT CAPACITY
 IF(CARGOES.GT.CAPACITY)GO TO 610
 IF(GRANTOUR(KVAR,2).LE.2)GO TO 770
 DO 780 L=1,GRANTOUR(KVAR,2)+1
 780 GRANTOUR(KVAR,L+4)=TOURS(SETHEAD,L+4)
 790 GRANTOUR(KVAR,2)=GRANTOUR(KVAR,2)+1
 GO TO 760
 770 DO 7702 L=1,GRANTOUR(KVAR,2)+1
 7702 GRANTOUR(KVAR,L+4)=TOUR(L)
 GO TO 790
C ELIMINATE BASE J FROM ROUTE K
 760 M=1
 DO 640 L=1,GRANTOUR(K,2)
 IF(GRANTOUR(K,L+4).EQ.GRANTOUR(K,J+4))GO TO 640
 GRANTOUR(K,M+4)=GRANTOUR(K,L+4)
 GRANTOUR(K,2)=M
 M=M+1
 640 CONTINUE
 ROUTOTAL=ROUTOTAL+PSAVINGS
 GRANTOUR(K,3)=GRANTOUR(K,3)+SAVINGS
 GRANTOUR(KVAR,3)=THISLGTH
 610 CONTINUE
 600 CONTINUE
 RETURN
 END
 SUBROUTINE DOUBLE(HUB)
 INTEGER HUB,ACFTYPE,TOURS,TOUR,SETHEAD,GRANTOUR,NTOUR(20)
 LOGICAL IDIDTHIS/.F./
 COMMON/PETALS/GRANTOUR(20,25),NUMPETAL/TOTALS/QDISTOTL,ROUTOTAL/SETHD/
```

```
&SETHEAD
 COMMON/ROUTES/KOUNT,TOURS(12,20),TOUR(15)/MATRIX/DISTANCE(60,60),BASES
&(10,60)/LOAD/CAPACITY
 DO 600 K=1,NUMPETAL
 IF(GRANTOUR(K,2).LE.2)GO TO 600
 KMINUS=K-1
 KPLUS=K+1
 IF(K.EQ.1)KMINUS=NUMPETAL
 IF(K.EQ.NUMPETAL)KPLUS=1
 DO 610 J=1,GRANTOUR(K,2)
 IF(GRANTOUR(K,2)-J)420,420,430
 420 JPLUS=5
 JPLUS2=5
 GO TO 3603
 430 JPLUS=J+5
 IF(GRANTOUR(K,2)-J.GE.2)GO TO 3603
 JPLUS2=5
 3603 IF(J-3)440,450,450
 440 IF(J.EQ.1)GO TO 460
 JMINUS=J-1+4
 JMINUS2=GRANTOUR(K,2)
 GO TO 470
 460 JMINUS=GRANTOUR(K,2)
 JMINUS2=JMINUS-1
 GO TO 470
 450 JMINUS=J-1+4
 JMINUS2=J-2+4
 470 IF(GRANTOUR(K,J+4).EQ.HUB.OR.GRANTOUR(K,JMINUS).EQ.HUB)
&GO TO 610
 SAVINGS=DISTANCE(GRANTOUR(K,JPLUS),GRANTOUR(K,JMINUS2))-(DISTANCE(
&GRANTOUR(K,JMINUS2),GRANTOUR(K,JMINUS))+DISTANCE(GRANTOUR(K,
&JMINUS),GRANTOUR(K,J+4))+DISTANCE(GRANTOUR(K,J+4),GRANTOUR(K,JPLUS)))
 KVAR=KPLUS
 620 OLENGTH=GRANTOUR(KVAR,3)
 DO 630 I=1,GRANTOUR(KVAR,2)
 630 TOUR(I+2)=GRANTOUR(KVAR,I+3)
 TOUR(1)=GRANTOUR(K,JMINUS)
 TOUR(2)=GRANTOUR(K,J+4)
   CALL LINSTSP(GRANTOUR(KVAR,2)+2,ACFTYPE)
 IF(IDIDTHIS)GO TO 670
 DO 680 L=1,GRANTOUR(KVAR,2)+2
 680 NTOUR(L)=TOURS(SETHEAD,L+4)
 670 THISLGTH=TOURS(SETHEAD,1)
 IF (IDIDTHIS)GO TO 700
 PSAVINGS=SAVINGS-(OLENGTH-THISLGTH)
 KVAR=KMINUS
 IDIDTHIS=.T.
 GO TO 620
 700 IDIDTHIS=.F.
 MSAVINGS=SAVINGS-(OLENGTH-THISLGTH)
 IF(PSAVINGS.GT.MSAVINGS)PSAVINGS=MSAVINGS
 IF(PSAVINGS.GT.0.00)GO TO 610
 IF(PSAVINGS-MSAVINGS)720,740,740
 720 KVAR=KPLUS
```

```
 DO 710 L=1,GRANTOUR(KVAR,2)+2
 710 CARGOES=CARGOES+BASES(NTOUR(L),5)-BASES(NTOUR(L),4)
C CHECK IF ADDING J & J+1 TO ROUTE K+1 EXCEEDS CAPACITY
 IF(CARGOES.GT.CAPACITY)GO TO 610
C ADD J & J+1 TO ROUTE K+1
 DO 750 L=1,GRANTOUR(KVAR,2)+2
 750 GRANTOUR(KVAR,L+4)=NTOUR(L)
C UPDATE NUMBER OF BASES IN TOUR K+1
 GRANTOUR(KVAR,2)=GRANTOUR(KVAR,2)+2
 GO TO 510
 740 DO 730 L=1,GRANTOUR(KVAR,2)+2
 730 CARGOES=CARGOES+BASES(TOURS(SETHEAD,L+4),5)-BASES(TOURS(SETHEAD,L+4
&),4)
 IF(CARGOES.GT.CAPACITY) GO TO 610
 DO 780 L=1,GRANTOUR(KVAR,2)+2
 780 GRANTOUR(KVAR,L+4)=TOURS(SETHEAD,L+4)
 GRANTOUR(KVAR,2)=GRANTOUR(KVAR,2)+2
C ELIMINATE BASES J & J+1 FROM ROUTE K
 510 M=1
 DO 640 L=1,GRANTOUR(K,2)
 IF(GRANTOUR(K,L+4).EQ.GRANTOUR(K,J+4))GO TO 640
 IF(GRANTOUR(K,L+4).EQ.GRANTOUR(K,JMINUS))GO TO 640
 GRANTOUR(K,M+4)=GRANTOUR(K,L+4)
 GRANTOUR(K,2)=M
 M=M+1
 640 CONTINUE
 ROUTOTAL=ROUTOTAL+PSAVINGS
 GRANTOUR(K,3)=GRANTOUR(K,3)+SAVINGS
 GRANTOUR(KVAR,3)=THISLGTH
 610 CONTINUE
 600 CONTINUE
 RETURN
 END
$       EXECUTE
$       LIMITS  20,25K
$       FILE    12,X11R,5L
$       DATA    I*
$       SELECTA BASEDATA
$       ENDJOB

*
```

APPENDIX B

SINGLE-HUB LOGAIR ROUTE SYSTEM

SIMULATION PROGRAM

```
$       PROGRAM RLMS
$       LIMITS  6,40K,,2K
$       PRMFL   H*,R,R,CACI/SIM2.5
$       FILE    *1
$       FILE    *2
$       FILE    R*,BIS
$       SYSOUT  C*
 PREAMBLE
 NORMALLY MODE IS REAL AND DIMENSION IS 0
 DEFINE SHPNUM,LANDINGS,FLT.NUM,HOW.MANY.BASES AS INTEGER VARIABLES
 DEFINE I,J,JJ,KM,IJ,INGRESS AS INTEGER VARIABLES
 DEFINE WATE,WAET,X AS VARIABLES
 DEFINE SAMPLE.LIST AS A 2-DIMENSIONAL, INTEGER ARRAY
 PERMANENT ENTITIES.....
   EVERY ROUTE  OWNS A NODE.LIST, SOME WAIT.FREIGHT, MAY
    BELONG TO A FLIGHT.PLAN
   EVERY BASE HAS A  (RTE.NUM(1/3),ID.NUM(2/3),RNKORDER(3/3)),
  A FST.DST, A SEC.DST, BELONGS TO A NODE.LIST,
    AND OWNS A WAREHOUSE
     DEFINE RTE.NUM,ID.NUM,RNKORDER AS INTEGER VARIABLES
   EVERY ALC HAS AN ID
     DEFINE ID AS AN INTEGER VARIABLE
 TEMPORARY ENTITIES.....
   EVERY AIRPLANE HAS A CAPACITY, A LOAD MAY
     OWN A MANIFEST, AND A FLIGHT.PLAN
   EVERY SHIPMENT HAS A (D.ROUTE(1/2),D.BASE(2/2),DESTINATION),
     A WEIGHT, A RLS.TIME, A SOURCE, MAY BELONG TO A
   WAREHOUSE, A WAIT.FREIGHT, AND A MANIFEST
     DEFINE DESTINATION, D.ROUTE, D.BASE, SOURCE AS INTEGER VARIABLE
 EVENT NOTICES INCLUDE PULSE, STOP.SIMULATION, GEN.CARGO
   EVERY ARRIVAL HAS AN AAIRPLANE AND A ABASE
   EVERY DEPARTURE HAS A DAIRPLANE AND A DROUTE
   EVERY TERMINATION HAS A TAIRPLANE
 TALLY TOT.TRANSIT.TIME AS THE SUM, AV.TRANSIT.TIME AS
  THE AVG, TTHISTO(0 TO 4 BY .5) AS THE HISTOGRAM, BIGTIME AS THE MAX,
   AND SMALLTIME AS THE MIN OF TRANSIT.TIME
 TALLY TON.DAYS AS THE SUM OF TONDAY
 TALLY TOTAL.TONNAGE AS THE SUM OF TONNAGE
 TALLY AIR.MILES AS THE SUM OF MILES.FLOWN
   DEFINE TRANSIT.TIME, TONDAY AS VARIABLES
   DEFINE MILES.FLOWN AS A DUMMY VARIABLE
   DEFINE TONNAGE AS A DUMMY VARIABLE
   DEFINE T.MILES AS A DUMMY VARIABLE
 THE SYSTEM HAS A RDMVAR RANDOM LINEAR VARIABLE
 THE SYSTEM HAS A HUB , A DEBASE , AN SOBASE
   DEFINE HUB, DEBASE, SOBASE AS  TEGER VARIABLES
   DEFINE RCARGO.TABLE AS A 2-DIMENSIONAL ARRAY
   DEFINE INFO.TABLE AS A 1-DIMENSIONAL, INTEGER ARRAY
 END
..
..

      G 'VAR
```

```
READ N.ALC
CREATE EACH ALC
  READ ID
RESERVE SAMPLE.LIST AS N.ALC BY 10
READ SAMPLE.LIST
LET JJ=1
LET KK=0
READ N.ROUTE,N.BASE
LET N.BASE=N.BASE+22
CREATE EACH ROUTE
CREATE EACH BASE
FOR EACH ROUTE, DO
  READ HOW.MANY.BASES
  LET KK=KK+HOW.MANY.BASES
  FOR EACH BASE, DO
    IF JJ LE BASE LE KK
    LET RTE.NUM(BASE)=ROUTE
    READ ID.NUM(BASE),RNKORDER(BASE),FST.DST(BASE)
      ,SEC.DST(BASE)
    FILE BASE IN NODE.LIST
    ALWAYS
  LOOP
  LET JJ=JJ+HOW.MANY.BASES
LOOP
LET N.BASE=N.BASE-22
RESERVE RCARGO.TABLE AS N.BASE BY N.BASE
RESERVE INFO.TABLE AS N.BASE
FOR DEBASE=1 TO N.BASE,DO
  FOR SOBASE=1 TO N.BASE,DO
    READ RCARGO.TABLE(SOBASE,DEBASE)
    LET RCARGO.TABLE(SOBASE,DEBASE)=RCARGO.TABLE(SOBASE,DEBASE)
    /365.00
  LOOP
LOOP
  FOR DEBASE=1 TO N.BASE,DO
    READ INFO.TABLE(DEBASE)
  LOOP
LET N.BASE=N.BASE+22
SCHEDULE A STOP.SIMULATION IN 93 DAYS
SCHEDULE A PULSE IN 15 MINUTES
SCHEDULE A GEN.CARGO NOW
''
''
START SIMULATION
''
''
''END OF SIMULATION REPORT
LET WTD.TRANS.TIME=TON.DAYS/TOTAL.TONNAGE
START NEW PAGE
IF LINE.V=1
PRINT 5 LINES LIKE THIS
                 SIMULATION OF A SINGLE HUB LOGAIR SYSTEM

                   THE HUB IS LOCATED AT TINKER AFB,OK
```

```
    SIMULATION RESULT FOR THE 4TH QTR 1979--
PRINT 1 LINE LIKE THIS
    ----------------------------------------
SKIP 3 LINES
ALWAYS
PRINT 5 LINES WITH BIGTIME,SMALLTIME,LANDINGS,AV.TRANSIT.TIME,
  WTD.TRANS.TIME LIKE THIS
      MAX TRANSIT TIME--  **.**       MIN TRANSIT TIME--  **.***
      NUMBER OF LANDINGS--  *****
      AVG TRANSIT TIME--  ***.** DAYS
      WEIGHTED AVG TRANSIT TIME--  ***.** DAYS
     ------------------------------------
PRINT 4 LINES LIKE THIS
      TRANSIT TIME DISTRIBUTION--

 0 TO 0.5    0.51 TO 1.0     1.01 TO 1.5     1.51 TO 2.0     2.01 TO 2.5
   DAYS         DAYS              DAYS           DAYS              DAYS
PRINT 1 LINE WITH TTHISTO(1),TTHISTO(2),TTHISTO(3),TTHISTO(4),
TTHISTO(5) LIKE THIS
  *****         *****            *****            *****            *****
SKIP 2 LINES
PRINT 2 LINES LIKE THIS
   2.51 TO 3.0     3.01 TO 3.5     3.51 TO 4.0
      DAYS            DAYS            DAYS
SKIP 1 LINE
PRINT 1 LINE WITH TTHISTO(6),TTHISTO(7),TTHISTO(8) LIKE THIS
     *****           *****           *****
STOP
END
''
''
EVENT PULSE
DEFINE SHPMNT,VISIT AS INTEGER VARIABLES
FOR EACH ROUTE
 ,DO
  LET FLT.NUM=FLT.NUM+1
  CREATE AN AIRPLANE CALLED FLT.NUM
IF ROUTE=1 GO TO C130 ELSE
IF ROUTE=2 GO TO C130 ELSE
IF ROUTE=6 GO TO C130 ELSE
IF ROUTE=9 GO TO C130 ELSE
IF ROUTE=18 GO TO C130 ELSE
IF ROUTE=19 GO TO C130 ELSE
   LET CAPACITY(FLT.NUM)=15.4
    GO TO NEXT
'C130' LET CAPACITY(FLT.NUM)=23.5
'NEXT' IF WAIT.FREIGHT(ROUTE) IS NOT EMPTY
  REMOVE THE FIRST SHPMNT FROM WAIT.FREIGHT(ROUTE)
   IF LOAD(FLT.NUM)+WEIGHT(SHPMNT) GT CAPACITY(FLT.NUM) GO TO THERE ELSE
  LET LOAD(FLT.NUM)=LOAD(FLT.NUM)+WEIGHT(SHPMNT)
  FILE SHPMNT IN MANIFEST(FLT.NUM)
  IF LOAD(FLT.NUM) GE CAPACITY(FLT.NUM) GO TO EXIT ELSE
GO TO NEXT
 ELSE
```

```
'EXIT' FILE ROUTE IN FLIGHT.PLAN(FLT.NUM)
  REMOVE THE FIRST VISIT FROM NODE.LIST(ROUTE)
  IF WEEKDAY.F(TIME.V)=1 GO TO SKIP ELSE
  IF WEEKDAY.F(TIME.V)=7 GO TO SKIP ELSE
'BACK' SCHEDULE AN ARRIVAL(FLT.NUM.,VISIT) IN FST.DST(VISIT) HOURS
  FILE VISIT FIRST IN NODE.LIST(ROUTE)
  CYCLE
'SKIP' IF SEC.DST(VISIT) LE 0 GO TO BACK ELSE
  LET X=SEC.DST(VISIT)
  FILE VISIT LAST IN NODE.LIST(ROUTE)
  REMOVE FIRST VISIT FROM NODE.LIST(ROUTE)
  SCHEDULE AN ARRIVAL(FLT.NUM,VISIT) IN X HOURS
  FILE VISIT FIRST IN NODE.LIST(ROUTE)
  CYCLE
'THERE' LET WATE=LOAD(FLT.NUM)+WEIGHT-CAPACITY(FLT.NUM)
IF WATE GE WEIGHT(SHPMNT) GO TO EXIT ELSE
  CALL SPLIT(SHPMNT,WATE,FLT.NUM)
  FILE SHPMNT FIRST IN WAIT.FREIGHT(ROUTE)
  GO TO NEXT
LOOP
SCHEDULE A PULSE IN 24 HOURS
RETURN
END
''
''
UPON ARRIVAL(AAIRPLANE,ABASE)
DEFINE AAIRPLANE,ABASE,AROUTE,SHPMNT AS INTEGER VARIABLES
LET LANDINGS=LANDINGS+1
REMOVE THE FIRST AROUTE FROM FLIGHT.PLAN(AAIRPLANE)
REMOVE THIS ABASE FROM NODE.LIST(AROUTE)
IF MANIFEST(AAIRPLANE) IS EMPTY GO TO SKIP ELSE
 FOR EVERY SHPMNT IN MANIFEST(AAIRPLANE)
,DO
  IF D.BASE(SHPMNT) NE ID.NUM(ABASE) CYCLE ELSE
  FOR EACH ALC, DO
    IF SOURCE(SHPMNT) NE ID CYCLE ELSE
    FOR IJ=1 TO 10, WITH SAMPLE.LIST(ALC,IJ)=D.BASE(SHPMNT),
      FIND THE FIRST CASE IF FOUND GO TO LBL3 ELSE
  LOOP
GO TO TEST
'LBL3' LET TRANSIT.TIME=TIME.V-RLS.TIME(SHPMNT)
LET TONDAY=TRANSIT.TIME*WEIGHT(SHPMNT)
LET TONNAGE=WEIGHT(SHPMNT)
'TEST' LET LOAD(AAIRPLANE)=LOAD(AAIRPLANE)-WEIGHT(SHPMNT)
REMOVE SHPMNT FROM MANIFEST(AAIRPLANE)
DESTROY THE SHIPMENT CALLED SHPMNT
LOOP
'SKIP'
''
''
WHILE WAREHOUSE(ABASE) IS NOT EMPTY
,DO
  REMOVE THE FIRST SHPMNT FROM WAREHOUSE(ABASE)
'BACK' IF LOAD(AAIRPLANE)+WEIGHT(SHPMNT) GT CAPACITY(AAIRPLANE)
```

```
    GO TO THERE ELSE
  LET LOAD(AAIRPLANE)=LOAD(AAIRPLANE)+WEIGHT(SHPMNT)
  LET RLS.TIME(SHPMNT)=TIME.V
  FILE SHPMNT IN MANIFEST(AAIRPLANE)
  IF LOAD(AAIRPLANE) GE CAPACITY(AAIRPLANE) GO TO LEAF ELSE
LOOP
GO TO LEAF
'THERE' LET WATE=LOAD(AAIRPLANE)+WEIGHT(SHPMNT)-CAPACITY(AAIRPLANE)
CALL SPLIT(SHPMNT,WATE,AAIRPLANE)
FILE SHPMNT FIRST IN WAREHOUSE(ABASE)
'LEAF' FILE ABASE LAST IN NODE.LIST(AROUTE)
FILE AROUTE IN FLIGHT.PLAN(AAIRPLANE)
SCHEDULE A DEPARTURE(AAIRPLANE,AROUTE) IN 1.5 HOURS
RETURN
END
''
''
EVENT GEN.CARGO
FOR SOBASE=1 TO 60, DO
  FOR DEBASE=1 TO 60, DO
    IF RCARGO.TABLE(SOBASE,DEBASE) LT 0.005
    CYCLE ELSE
    LET SHPNUM=SHPNUM+1
    CREATE A SHIPMENT CALLED SHPNUM
    LET WEIGHT(SHPNUM)=RDMVAR*RCARGO.TABLE(SOBASE,DEBASE)
    LET D.ROUTE(SHPNUM)=INFO.TABLE(DEBASE)
    LET D.BASE(SHPNUM)=DEBASE
    LET SOURCE(SHPNUM)=SOBASE
    IF SOBASE=15 LET ROUTE=D.ROUTE(SHPNUM)
    LET RLS.TIME(SHPNUM)=TIME.V
    FILE SHPNUM IN WAIT.FREIGHT(ROUTE)
    CYCLE ELSE
    FOR EACH BASE,DO IF ID.NUM(BASE)=SOURCE(SHPNUM) JUMP AHEAD
    ELSE LOOP
    PRINT 1 LINE LIKE THIS
      ERROR IN GEN.CARGO<<<<<<<<<<<<<<<<<<<<
    TRACE
 STOP
    HERE
    FILE SHPNUM IN WAREHOUSE(BASE)
  LOOP
LOOP
SCHEDULE A GEN.CARGO IN 24 HOURS
RETURN
END
''
''
UPON DEPARTURE(DAIRPLANE,DROUTE)
DEFINE DAIRPLANE.DBASE,NBASE AS INTEGER VARIABLES
REMOVE FIRST DBASE FROM NODE.LIST(DROUTE)
IF ID.NUM(DBASE)=HUB SCHEDULE A TERMINATION(DAIRPLANE) IN
  FST.DST(DBASE) HOURS
GO TO LBL
ELSE
```

```
IF SEC.DST(DBASE) GT 0 GO TO SKIP ELSE
'BACK' SCHEDULE AN ARRIVAL(DAIRPLANE,DBASE) IN FST.DST(DBASE) HOURS
'LBL' FILE DBASE LAST IN NODE.LIST(DROUTE)
RETURN
'SKIP' IF WEEKDAY.F(TIME.V) NE 1
IF WEEKDAY.F(TIME.V) NE 7
  GO TO BACK
   ELSE
  ALWAYS
REMOVE FIRST NBASE FROM NODE.LIST(DROUTE)
IF ID.NUM(NBASE)=HUB SCHEDULE A TERMINATION(DAIRPLANE)
  IN SEC.DST(DBASE) HOURS
GO TO PLACE
ELSE SCHEDULE AN ARRIVAL(DAIRPLANE,NBASE) IN SEC.DST(DBASE) HOURS
'PLACE' FILE DBASE LAST IN NODE.LIST(DROUTE)
FILE NBASE AFTER DBASE IN NODE.LIST(DROUTE)
RETURN
END
''
''
UPON STOP.SIMULATION
FOR EACH GEN.CARGO IN EV.S(I.GEN.CARGO),DO
  CANCEL THE GEN.CARGO
  DESTROY THE GEN.CARGO
LOOP
FOR EACH PULSE IN EV.S(I.PULSE),DO
  CANCEL THE PULSE
  DESTROY THE PULSE
LOOP
RETURN
END
''
''
UPON TERMINATION(TAIRPLANE)
DEFINE TAIRPLANE,SHPMNT,TROUTE AS INTEGER VARIABLES
IF MANIFEST(TAIRPLANE) IS EMPTY GO TO SKIP ELSE
FOR EVERY SHPMNT IN MANIFEST(TAIRPLANE),DO
IF D.BASE(SHPMNT)=HUB
  FOR EACH ALC,DO
   IF SOURCE(SHPMNT) NE ID CYCLE ELSE
   FOR IJ=1 TO 10, WITH SAMPLE.LIST(ALC,IJ)=D.BASE(SHPMNT),
   FIND THE FIRST CASE IF FOUND GO TO LBL2 ELSE
  LOOP
GO TO TEST
'LBL2' LET TRANSIT.TIME=TIME.V-RLS.TIME(SHPMNT)
LET TONDAY=TRANSIT.TIME*WEIGHT(SHPMNT)
 LET TONNAGE=WEIGHT(SHPMNT)
'TEST' REMOVE THE SHPMNT FROM MANIFEST(TAIRPLANE)
DESTROY THE SHIPMENT CALLED SHPMNT
CYCLE
ELSE
REMOVE THE SHPMNT FROM MANIFEST(TAIRPLANE)
LET ROUTE=D.ROUTE(SHPMNT)
FILE SHPMNT IN WAIT.FREIGHT(ROUTE)
```

```
LOOP
'SKIP' REMOVE THE FIRST TROUTE FROM FLIGHT.PLAN(TAIRPLANE)
 DESTROY THE AIRPLANE CALLED TAIRPLANE
RETURN
END
''
''
ROUTINE FOR SPLIT(SSHIP,POUNDS,SACFT)
DEFINE SSHIP,SACFT AS INTEGER VARIABLES
LET SHPNUM=SHPNUM+1
CREATE A SHIPMENT CALLED SHPNUM
 LET DESTINATION(SHPNUM)=DESTINATION(SSHIP)
LET RLS.TIME(SHPNUM)=RLS.TIME(SSHIP)
LET SOURCE(SHPNUM)=SOURCE(SSHIP)
LET WEIGHT(SHPNUM)=POUNDS
LET WEIGHT(SSHIP)=WEIGHT(SSHIP)-POUNDS
FILE SHPNUM IN MANIFEST(SACFT)
RETURN
END
$       LOWLOAD
$       OPTION  FORTRAN,GO
$       LIBRARY SL
$       SOURCE
$       EXECUTE
$       LIMITS  30,70K,-3K,4K
$       FILE    B*,BIR
$       PRMFL   SL,R,S,CACI/SIM2LIB
$       PRMFL   17,R,S,CACI/SIMERR
$       DATA    I*
$       SELECTA BIGMATIX
$       ENDJOB

*
```

APPENDIX C

SINGLE-HUB ROUTE ITINERARY

Route ID	Type A/c	Station	Zulu Time ARR	Zulu Time DEP	Cargo tons Inbound	% WT Utilization	NM From Departure
1	L-100	Tinker	Orig	1100	-	-	-
		Kelly	1230	1400	21.5	100	358
		Tinker	1530	Term	21.5	100	358
2	L-100	Tinker	Orig	1100	-	-	-
		Barksdale	1215	1345	11.06	51.4	253
		England	1425	1555	10.26	47.7	92
		Kelly	1725	1855	9.28	43.2	327
		Tinker	2025	Term	21.5	100	358
3	L-188	Tinker	Orig	1100	-	-	-
		Davis-Monthan	1320	1550	5.41	35.1	698
		Holloman	1650	1820	3.91	25.4	244
		Kelly	1940	2110	3.39	22.0	445
		Tinker	2230	Term	11.63	75.5	358
4	L-188	Tinker	Orig	1100	-	-	-
		MacDill	1400	1530	14.94	97.0	882
		Homestead	1622	1752	10.62	69.0	181
		Key West*	1827	1957	11.63	75.5	89
		Tinker	2317	Term	11.52	74.8	1045

*Weekday service only; Route 4 reduced by 69 NM on weekends

Route ID	Type A/C	Station	Zulu Time ARR	DEP	Cargo tons Inbound	%WT Utilization	NM From Departure
5	L-188	Tinker	Orig	1100	-	-	-
		Eglin	1310	1440	14.76	95.8	622
		Tyndall	1510	1640	13.29	86.3	55
		Patrick	1750	1920	10.07	65.4	280
		Jacksonville*	2005	2135	9.49	61.6	135
		Tinker	0025	Term	11.26	73.1	860
6	L-100	Tinker	Orig	1100	-	-	-
		Robins	1400	1530	21.5	100	711
		Tinker	1830	Term	21.5	100	711
7	L-188	Tinker	Orig	1100	-	-	-
		Columbus	1240	1410	14.8	96.1	456
		Robins	1515	1645	14.04	91.2	254
		Charleston	1735	1905	6.27	40.7	180
		Tinker	2155	Term	3.23	20.9	883
8	L-188	Tinker	Orig	1100	-	-	-
		Little Rock	1205	1335	10.79	70.1	258
		Shaw	1535	1705	10.16	66.0	506
		Seymour-Johnson	1800	1930	10.38	67.4	182
		Blytheville	2130	2300	7.65	49.7	588
		Tinker	0020	Term	7.49	48.6	365

*Weekday service only; Route 5 reduced by 36 NM on weekends.

Route ID	Type A/C	Station	Zulu ARR	Time DEP	Cargo tons Inbound	% WT Utili-zation	NM From Depar-ture
10	L-188	Tinker	Orig	1100	-	-	-
		McGuire	1430	1600	8.2	53.2	1117
		Tinker	1930	Term	15.4	100	1117
11	L-188	Tinker	Orig	1100	-	-	-
		Dover	1430	1600	12.51		1070
		Tinker	1930	Term	15.4	100	1070
12	L-188	Tinker	Orig	1100	-	-	-
		Langley	1420	1550	3.15	20.4	1024
		Dover	1635	1805	1.5	9.7	130
		McGuire	1825	1955	9.67	62.8	65
		Tinker	2325	Term	14.04	91.2	1117
13	L-188	Tinker	Orig	1100	-	-	-
		Scott	1230	1400	5.36	34.8	408
		Plattsburgh	1640	1810	3.72	24.2	819
		Loring	1915	2045	2.66	17.3	272
		Tinker	0115	Term	2.95	19.2	1495
14	L-188	Tinker	Orig	1100	-	-	-
		Wurtsmith	1340	1510	5.36	34.8	840
		Selfridge	1600	1730	4.15	26.9	115
		Griffiss	1850	2020	3.7	24.0	326
		Tinker	2350	Term	12.11	78.6	1118

Route ID	Type A/C	Station	Zulu Time ARR	Zulu Time DEP	Cargo tons Inbound	% WT Utili-zation	NM From Depar-ture
15	L-188	Tinker	Orig	1100	-	-	-
		Whiteman	1205	1335	8.38	54.4	270
		K.I.Sawyer	1520	1650	7.62	49.5	536
		Duluth	1745	1915	7.24	47.0	200
		Grand Forks	2015	2145	7.05	45.8	225
		Offutt	2315	0045	6.79	44.1	410
		Tinker	0205	Term	5.38	35.0	346
16	L-188	Tinker	Orig	1100	-	-	-
		Ellsworth	1300	1430	7.87	51.1	588
		Minot	1535	1705	7.5	48.7	268
		Malmstrom	1835	2005	7.24	47.0	404
		F.E.Warren	2145	2315	5.69	36.9	470
		Tinker	0100	Term	4.12	26.8	490
17	L-188	Tinker	Orig	1100	-	-	-
		Fairchild	1430	1600	12.34	80.1	1164
		McChord	1655	1825	11.78	76.5	202
		Mt. Home	1945	2115	8.64	56.1	374
		Tinker	0025	Term	7.53	48.9	972
18	L-100	Tinker	Orig	1100	-	-	-
		Hill	1430	1600	21.5	100	766
		Tinker	1930	Term	21.5	100	766

Route ID	Type A/C	Station	Zulu Time ARR	Zulu Time DEP	Cargo tons Inbound	% WT Utili-zation	NM From Depar-ture
19	L-100	Tinker	Orig	1100	-	-	-
		McClellan	1530	1700	18.57	86.4	1165
		Tinker	2130	Term	21.5	100	1165
20	L-188	Tinker	Orig	1100	-	-	-
		Travis	1450	1620	12.71	82.5	1208
		McClellan	1650	1820	1.28	8.3	35
		Tinker	2200	Term	15.4	100	1165
21	L-188	Tinker	Orig	1100	-	-	-
		Peterson	1230	1400	1.84	11.9	405
		Hill	1540	1710	2.19	14.2	362
		McClellan	1850	2020	9.24	60.0	458
		Tinker	2400	Term	10.97	71.2	1165
22	L-188	Tinker	Orig	1100	-	-	-
		Norton	1415	1545	15.05	97.7	986
		Nellis	1635	1805	10.45	67.9	169
		Tinker	2055	Term	9.24	60.0	863
23	L-188	Tinker	Orig	1100	-	-	-
		Cannon	1210	1340	7.41	48.1	298
		Luke	1520	1650	6.76	43.9	456
		Kirtland	1800	1930	5.53	35.9	302
		Tinker	2110	Term	4.96	32.2	453

APPENDIX D

ANALYSIS OF RANDOM SAMPLE OF LOGAIR SHIPMENT WEIGHTS DURING OCT, NOV, DEC 1979 (20)

AD-A088 775 AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL--ETC F/G 1/5
THE LOGAIR ROUTE STRUCTURE: AN EXPLORATION OF THE SINGLE-HUB CO--ETC(U)
JUN 80 M O PAYNE, D A SCOTT

UNCLASSIFIED AFIT-LSSR-40-80 NL

2 of 2
AD A
088775

END
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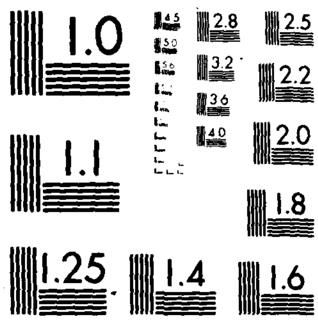


MICROCOPY RESOLUTION TEST CHART

```
RUN NAME          CARGO SHIPMENT SAMPLE
VARIABLE LIST     WEIGHT
N OF CASES        768
INPUT FORMAT      FREEFIELD
INPUT MEDIUM      CARD
IF                (WEIGHT LE 50) VAR=1
IF                (WEIGHT LE 100 AND GT 50) VAR=2
IF                (WEIGHT LE 150 AND GT 100) VAR=3
IF                (WEIGHT LE 200 AND GT 150) VAR=4
IF                (WEIGHT LE 250 AND GT 200) VAR=5
IF                (WEIGHT LE 300 AND GT 250) VAR=6
IF                (WEIGHT LE 350 AND GT 300) VAR=7
IF                (WEIGHT LE 400 AND GT 350) VAR=8
IF                (WEIGHT LE 450 AND GT 400) VAR=9
IF                (WEIGHT LE 500 AND GT 450) VAR=10

RANSPACE ADDED. INCREASE LIMITS FOR NEXT RUN ****

IF                (WEIGHT GT 500) VAR=11
COMPUTE           NEWVAR=LN(WEIGHT)
VALUE LABELS      VAR (1) LT 50 (2) 50-100 (3) 100-150
                  (4) 150-200 (5) 200-250 (6) 250-300 (7) 300-350
                  (8) 350-400 (9) 400-450 (10) 450-500
                  (11) OVER 500
FREQUENCIES       INTEGER=VAR(1,11)
F WORKSPACE ARE AVAILABLE TO THIS PROCEDURE *****
OPTIONS           8
STATISTICS        ALL

EM REQUIRES       67 WORDS OF SPACE

READ INPUT DATA
```

```
1 36 4 4 8 3 24 30 9 222 252 200 27 9 22 17 2 68 30 2 58 2 68 30
2 50 3 16 44 92 12 141 10 12 25 13 12 112 2 50 250 246 2520 66
23 46 422 27 75 17 18 22 800 3 3 1 50 320 8 4 1 4 3 14 48 2500 23
285 2 2 44 4 81 1 420 40 84 16 96 3 27 36 26 4 114 28 15 3 4 1 7 90
2 22 63 1 1 8 4 30 224 14 71 450 6 28 39 229 91 80 432 56 3 9
59 1 77 1 3 456 1 140 12 47 16 2 2 6 1 3000 26 18 14 22 1 1 32
8 2 12 10 50 5 20 9 8 22 85 1 3 16 2 15 3 12 2 2 585 1 27 7
109 53 1 48 3 18 39 1 27 4 2 19 24 1920 6 3 1 22 21 4 26
110 1 20 42 15 9 1 1 1 705 115 28 10 6 13 47 2 5 3 1 31 2 3
20 1 309 20 1 5 5 2 1 7 48 41 18 29 5 12 36 580 168 79 1 10 4 2 8 99 55
10 110 4 18 2 45 45 1 2 113 4 18 2 14 53 19 9 1 2
5 1 1 22 32 90 1 2 21 12 530 2900 44 4 12 19 72 14 24 11 1 2 6 24 42 3
2 1 11 20 32 2 1 5 15 8 86 46 5 2 1 42 56 42 27 210 3 28 3 45 19 130
8 3 13 42 23 6 3 5 1 5 18 9 45 100 30 198 1 19 10 1 8 3 90 4 123
1125 44 48 325 51 7 20 195 132 842 2200 92 10 11 6 17 10 29 6 900
4 40 10 210 5 3 41 1 17 20 20 17 7 9 24 14 1 8 31 32 31 123 7
56 22 6 39 40 210 7 48 38 39 11 2 4 10 591 32 4 28 22 17 122
6 6 11 1 1 123 12 54 122 32 21 2 1 1 2 5 2 4 28 28 20 11 4 1 2 5
150 36 123 1 50 39 2 2 10 122 16 160 49 122 1 220 66 3 42 48
1 750 2 3 8 11 67 195 6 31 878 3 170 1 1 15 40 1560 17 24
218 104 701 1 1 27 18 26 285 4 3 30 165 13 44 84 44 54 8 67
249 2 1 6 5 3 10 72 4 1 3 1250 64 50 1 4 5 8 12 10 40 16 8
13 3 27 7 78 14 7 26 236 16 325 2 15 140 150 85 1 1 9 465
122 1 1 60 123 4 12 11 210 16 9 2 15 11 35 61 12 40 76 20 9
878 13 3130 22 7 175 57 25 6 100 25 36 16 6 5 66 37 1 1 1
220 50 40 248 84 1 32 15 66 8 1466 11 47 84 13 264 220 160
3 3 60 70 2 123 4 7 20 7 4 16 13 129 40 4 5 67 9 20 132
2 5 10 4 10 27 51 9 9 1 2 15 1 24 54 782 39 74 81 1 3
3 200 30 5 2 19 32 3 7 2 1 5 10 9 2 15 4 129 7 1 96 64 34
2 1 50 13 1 1 190 77 1 16 145 23 7 6 12 2 16 26 8 90 75
54 1 580 7 38 1 3 15 11 70 35 210 37 186 1 1 11 5 15 3
14 5 1 44 59 18 17 69 42 2 6 70 83 85 2 29 360 120 168
2 127 49 12 100 49 2 11 74 2 1640 185 39 10 40 2 1 30 2 1 1
11 14 2 28 1 1 6 1 17 193 22 5 600 31 1 2 3 78 2 108 29
31 1 8 110 2 28 38 1 2 215 40 2 12 21 2 54 1 47 238 2 5
```

LABEL CATEGORY	CODE	ABSOLUTE FREQUENCY	RELATIVE FREQUENCY (PERCENT)	ADJUSTED FREQUENCY (PERCENT)	CUMULATIVE ADJ FREQ (PERCENT)
LT 50	1	583	75.9	75.9	75.9
50-100	2	74	9.6	9.6	85.5
100-150	3	34	4.4	4.4	90.0
150-200	4	16	2.1	2.1	92.1
200-250	5	19	2.5	2.5	94.5
250-300	6	4	0.5	0.5	95.1
300-350	7	4	0.5	0.5	95.6
350-400	8	1	0.1	0.1	95.7
400-450	9	4	0.5	0.5	96.2
450-500	10	2	0.3	0.3	96.5
OVER 500	11	27	3.5	3.5	100.0
	TOTAL	768	100.0	100.0	

MEAN	1.829	STD ERR	0.078
MODE	1.000	STD DEV	2.149
KURTOSIS	10.467	SKEWNESS	3.289
MINIMUM	1.000	MAXIMUM	11.000
VALID CASES	768	MISSING CASES	0
MEDIAN	1.159		
VARIANCE	4.616		
RANGE	10.000		

```
     I
 1   *****************************           583
     I  LT 50
     I
     I
 2   *****       74
     I  50-100
     I
     I
 3   ***      34
     I  100-150
     I
     I
 4   **      16
     I  150-200
     I
     I
 5   **      19
     I  200-250
     I
     I
 6   *       4
     I  250-300
     I
     I
 7   *       4
     I  300-350
     I
     I
 8   *       1
     I  350-400
     I
     I
 9   *       4
     I  400-450
     I
     I
10   *       2
     I  450-500
     I
     I
11   **      27
     I  OVER 500
     I
     I.........I.........I.........I.........I.........I
     0        200       400       600       800      1000
     FREQUENCY
```

APPENDIX E

SYSTEM TRANSIT TIME*: FY 79 LOGAIR

ROUTE STRUCTURE

(Actual Performance - Oct, Nov, Dec 79)

(25; 26; 32)

*System Transit Time adjusted for Hold Time

Origin : Wright-Patterson AFB						
Destination	# Shipments (S_{ij})	Avg. Reported Transit Time	Avg. Hold Time	Rpt. TT-Hold Time (TT_{ij})	Avg. Daily Cargo Demand (W_{ij})	$W_{ij} \times TT_{ij}$
Homestead	35	106.28	44.24	62.04	0.126	7.812
Selfridge	186	70.49	18.30	2.19	0.044	0.096
Tyndall	86	66.96	37.41	29.55	0.060	1.773
Plattsburgh	680	22.16	13.66	8.50	0.077	0.655
Pease	522	18.71	14.34	4.37	0.438	1.914
Blytheville	180	160.8	33.15	127.65	0.082	10.467
Norton	289	65.32	39.08	26.24	0.318	8.344
Fairchild	27	116.23	28.81	87.42	0.027	2.360
McChord	411	93.90	18.19	75.71	0.178	13.476
Patrick	57	76.55	35.94	40.61	0.046	1.868

Origin: Hill AFB

Destination	S_{ij}	Rpt.T.T.	Avg. H.T.	TT_{ij}	W_{ij}	$W_{ij} \times TT_{ij}$
Barksdale	103	82.81	44.29	38.52	0.203	7.819
Blytheville	58	195.54	52.16	143.38	0.238	34.124
Charleston	262	86.11	37.58	48.53	0.260	12.618
Duluth	96	72.87	42.81	30.06	0.047	1.413
Davis-Monthan	253	42.28	38.03	4.25	0.184	0.782
F.E. Warren	224	60.98	45.68	15.30	0.186	2.846
Langley	381	83.33	34.20	49.13	0.244	11.988
Luke	1370	46.28	36.30	9.98	0.537	5.359
MacDill	537	97.44	37.44	60.00	0.304	18.240
Norton	2148	54.77	45.14	9.63	2.192	21.109

Origin: McClellan AFB

Destination	S_{ij}	Rpt.T.T.	Avg. H.T.	TT_{ij}	W_{ij}	$W_{ij} \times TT_{ij}$
Kirtland	119	83.25	16.15	67.10	0.611	40.998
Duluth	146	61.40	27.75	33.65	0.110	3.702
Hill	2000	37.49	17.61	19.88	2.082	41.390
Holloman	244	90.65	17.56	73.09	0.151	11.036
Langley	274	94.93	41.58	53.35	0.367	19.579
MacDill	655	84.88	17.30	67.58	0.690	46.630
Wurtsmith	203	93.82	25.85	67.97	0.112	7.613
Plattsburgh	802	79.39	16.47	62.92	0.584	36.745
McChord	161	60.04	30.86	29.18	0.219	6.390
Tinker	315	77.20	15.02	62.18	0.132	8.028

Origin: Kelly AFB

Destination	S_{ij}	Rpt.T.T.	Avg. H.T.	TT_{ij}	W_{ij}	$W_{ij} \times TT_{ij}$
Cannon	346	91.41	25.03	66.38	0.164	10.886
Davis-Monthan	463	89.32	28.10	61.22	0.471	28.834
F.E. Warren	53	102.56	27.46	75.10	0.068	5.107
Wright-Patt.	1063	87.07	53.25	33.82	3.285	111.099
Little Rock	1280	36.51	26.20	10.31	0.608	6.268
MacDill	296	98.41	42.01	56.40	0.613	34.573
Wurtsmith	147	98.45	40.62	57.83	0.112	6.477
Plattsburgh	381	90.04	35.49	54.55	0.159	8.673
McChord	955	53.09	33.05	70.04	2.011	40.300
Tinker	52	69.87	64.68	5.19	7.216	37.451

Origin: Tinker AFB						
Destination	S_{ij}	Rpt T.T.	Avg. H.T.	TT_{ij}	W_{ij}	$W_{ij} \times TT_{ij}$
Kirtland	235	94.37	26.97	67.40	0.066	4.448
Duluth	194	71.47	41.69	29.78	0.038	1.132
Dover	1296	69.54	42.23	27.31	0.340	9.285
Malmstrom	114	98.27	22.91	75.36	0.090	6.782
Hill	1881	61.39	31.77	29.62	1.077	31.900
Minot	404	128.07	23.96	104.11	0.384	39.978
Selfridge	329	63.88	38.20	25.68	0.159	4.083
Plattsburgh	785	62.88	34.51	28.37	0.493	13.986
Norton	2205	98.15	27.17	70.98	1.093	77.581
Shaw	501	80.79	35.87	44.92	0.071	3.189

Origin: Robins AFB

Destination	S_{ij}	Rpt T.T.	Avg. H.T.	TT_{ij}	W_{ij}	$W_{ij} \times TT_{ij}$
Scott	137	90.42	45.69	44.73	0.178	7.962
Seymour-Johnson	2193	70.27	17.19	3.08	0.699	2.153
Langley	1837	21.83	16.05	5.78	0.342	1.977
Minot	257	151.80	22.53	129.27	0.150	19.391
Nellis	679	93.82	22.53	71.29	0.288	20.532
Wurtsmith	478	77.10	23.22	53.88	0.214	11.530
Pease	954	69.52	28.95	40.57	0.384	15.579
Grand Forks	484	77.46	33.87	43.59	0.142	6.189
Norton	2567	53.47	34.91	18.56	0.959	17.800
Shaw	1473	25.72	18.11	7.61	0.233	1.773

$$\text{Weighted System Transit Time} = \frac{\Sigma\Sigma(W_{ij} \cdot TT_{ij})}{\Sigma\Sigma W_{ij}} = \frac{974.258}{32.956} = \begin{array}{l}29.56 \text{ hours or} \\ 1.23 \text{ days}\end{array}$$

$$\text{Unweighted System Transit Time} = \frac{\Sigma\Sigma(S_{ij} \cdot TT_{ij})}{\Sigma\Sigma S_{ij}} = \frac{1207311}{36863} = \begin{array}{l}32.75 \text{ hours or} \\ 1.36 \text{ days}\end{array}$$

APPENDIX F

COMPARISON OF CONTRACT COSTS (28)

	FY 80 System	Single-Hub System
L-100 Mileage	4,530,714 NM	3,522,980 NM
L-100 Mileage x $3.5259/mi	$15,975,000	$12,422,000
L-188 Mileage	8,377,311 NM	13,491,525 NM
L-188 Mileage x $2.4128/mi	$20,213,000	$32,552,000
Landings	30,587	29,722
Landings x $250/landing	$7,647,000	$7,431,000
5% Revenue Tax	$1,335,000	$1,335,000
Fuel Cost Above Contract	$2,463,000	$3,247,000
Total Cost	$47,633,000	$56,987,000

Difference: $9,354,000

or

an increase of 19.6%

NOTE: All dollars to nearest $1,000

APPENDIX G

TRANSIT TIME VARIANCES FOR THE

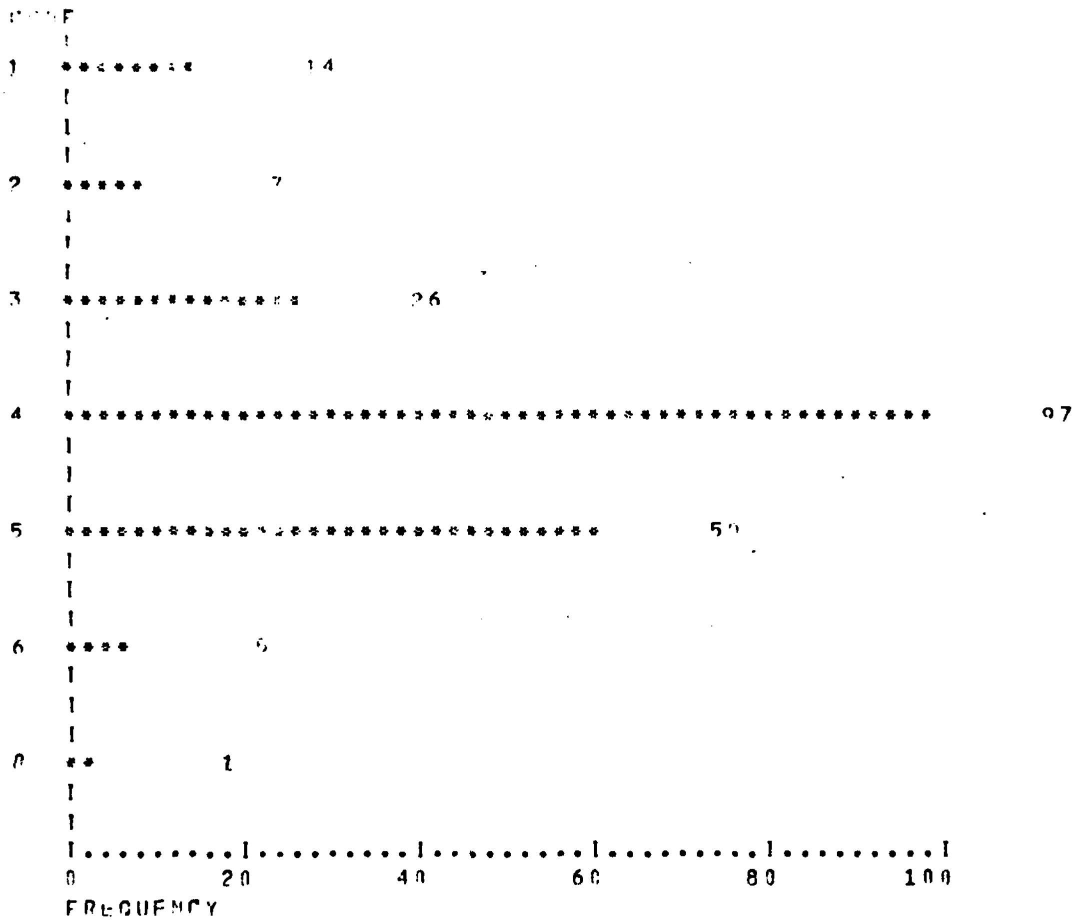
SINGLE-HUB SYSTEM

```
RUN NAME          CARGO SHIPMENT SAMPLE
VARIABLE LIST     TIME
N OF CASES        209
INPUT FORMAT      FREEFIELD
INPUT MEDIUM      CARD
IF                (TIME LE .25) VAR=1
IF                (TIME LE .50 AND GT .25) VAR=2
IF                (TIME LE .75 AND GT .50) VAR=3
IF                (TIME LE 1.00 AND GT .75) VAR=4
IF                (TIME LE 1.25 AND GT 1.00) VAR=5
IF                (TIME LE 1.50 AND GT 1.25) VAR=6
IF                (TIME LE 1.75 AND GT 1.50) VAR=7
IF                (TIME LE 2.00 AND GT 1.75) VAR=8
FREQUENCIES       INTEGER=VAR(1,8)
RDS OF WORKSPACE ARE AVAILABLE TO THIS PROCEDURE *****
OPTIONS           8
STATISTICS        ALL

PROBLEM REQUIRES       49 WORDS OF SPACE

READ INPUT DATA
```

CODE	ABSOLUTE FREQUENCY	RELATIVE FREQUENCY (PERCENT)	ADJUSTED FREQUENCY (PERCENT)	CUMULATIVE ADJ FREQ (PERCENT)
1	14	6.7	6.7	6.7
2	7	3.3	3.3	10.0
3	26	12.4	12.4	22.5
4	97	46.4	46.4	68.9
5	59	28.2	28.2	97.1
6	5	2.4	2.4	99.5
8	1	0.5	0.5	100.0
TOTAL	209	100.0	100.0	



MEAN	0.879	STD ERR	0.019
MODE	0.750	STD DEV	0.281
KURTOSIS	1.639	SKEWNESS	-0.962
MINIMUM	0.050	MAXIMUM	1.840
VALID CASES	209	MISSING CASES	0

MEDIAN	0.910
VARIANCE	0.079
RANGE	1.790

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